A REVIEW OF LITERATURE ON SYSTEMIC DIAGNOSTIC TOOLS AND MULTIMETHODOLOGY

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GLOSSARY OF TERMS

Paradigm: a general set of philosophical assumptions defining the nature of an intervention or research. It covers ontology (entities assumed to exist), epistemology (possibilities of, and limitations on the nature of valid knowledge), ethics or axiology (what is valued or considered right), and methodology.

Methodology: a structured set of guidelines or activities to assist people in undertaking research or interventions. Consist of various techniques.

Technique or method: primary activities or sequence of operations that have a clear and well defined purpose within the context of a methodology.

Tool: technique and/or methodology.

1. INTRODUCTION

The sugarcane supply and processing system is complex and is characterised by large numbers of autonomous, but mutually interacting stakeholders (Bodhanya, 2011; Bezuidenhout *et al*., 2013). These stakeholders therefore, are likely to have varying goals which lead to competing objectives within the system (Gerwel *et al*., 2011). Complex networks, as Bezuidenhout *et al*. (2012a) state, exhibit non-linearity, internal feedback, coupled agents, constant change, emergence, co-evolution, counterintuitive behaviour, and trade-offs. Christopher *et al*. (2011) noted that some of these characteristics can only be analysed by considering the entire system. Thus, any effort in supply chain improvement should be systemic (Sweeney, 1999).

Agri-industrial chains, like other supply chain, are made up of different dimensions which, in a case of any intervention, should be considered holistically. These constructs fall between both hard and soft system paradigms (Cooper *et al*., 1997). The agri-industrial supply system constructs, as stated in Bezuidenhout *et al*. (2013), are: biophysical, collaboration, culture, future strategy, economics, environment, history, information sharing, political forces, and rules, laws and structures.

The aim of this document is to review various tools that are (or can be) used to diagnose agri-industrial supply chains and also to review procedures that are used to combine these different tools in interventions. The first section discusses mutimethodology as a way of combining tools. Section 3 reviews certain systemic and cause and effect tools that are currently used in supply chain management and those that carry a potential. Section 4 is synthesis and conclusion where the tools in Section 3 are discussed along multimethodology within the ten agri-industrial chain dimensions. Section 5 contains a PhD project proposal.

2. MULTIMETHODOLOGY

Multimethodology is the combined use of different methodologies, or parts thereof, within a single intervention (Mingers and Brocklesby, 1997). Rosenhead and Mingers (2001: xiv) view multimethodology as a creative combination of methodologies and techniques for complex interventions. Multimethodogy is thus, a form of methodological pluralism that is premised on a multi-paradigm approach and as noted by Mingers and Gill (1997), “it is not a name of a methodology or even of a specific way of combining methodologies together but rather, a whole area of utilising a plurality of methodologies and techniques”. Multimethodology thus, utilises methods and techniques which are both qualitative and quantitative (Mingers, 2000), and both hard and soft approaches can be followed (Sterman, 1988; Mingers and Gill, 1997).

Methodological pluralism as defined by Jackson (1999) is the combined use of different methodologies and techniques in systems practice (Jackson, 1997; Jackson, 1999). Those advocating for methodological pluralism allude to the fact that the real world is complex and multidimensional whilst particular paradigms and methodologies only focus on specific aspects (Mingers and Brocklesby, 1997; Mingers, 2003a; Zawedde *et al*., 2010) Methodological pluralism, as noted by Andrew (2001), views all methods as complementary. It therefore, appreciates the strengths and theoretical grounding of various tools (Jackson, 1999; Jackson, 2003). Midgley (1998) states that pluralism encourages theoretical development and suggests ways in which different tools can be appropriately fitted to a variety of problems areas.

The development of methodological pluralism can be traced back to Jackson and Keys’ (1984) System of Systems Methodologies and Flood and Jackson’s (1991) Total Systems Intervention (Luckett, 2003). The System of Systems Methodologies (SOSM) provides a classification for methodology selection based on the strengths and circumstances under which each approach may best be utilised. It groups methodologies according to problem context categorisation (Flood and Jackson, 1991). The problem context, as categorised by Flood and Jackson (1991), is made up of two dimensions *viz*. systems complexity (simple to complex) and stakeholder complexity (unitary, pluralist, and coercive). The SOSM thus, uses an "ideal" two-dimensional grid as a criterion to select system methodologies; one side defining the complexity of a system under investigation and the other, the nature of relationships between participants. The SOSM is based on the idea that "methodologies from different paradigms make particular assumptions about the context within which they will be used" and therefore, "a methodology is most appropriate for a context matching its assumptions" (Mingers and Brocklesby, 1997: 492).

According to Clark (2001) the SOSM uses "methodology selection" as an attempt to pluralism. However, the SOSM does not outline a procedure on how to on apply these methodologies (Clark, 2001). The SOSM approach is also unable to separate techniques from a methodology, that is, methodology selection translates to using all techniques within that given methodology. For example, if one chooses the Theory of Constraints methodology, then s/he inevitably adopts the current reality tree, evaporating cloud, future reality tree, etc.

Total Systems Intervention (TSI) views the problem context as a mess (Flood, 1995) and operationalises pluralism by providing guidance for the use of a combination of methodologies (Luckett, 2003).The methodology is made up of three recursive phases *viz.* creativity, choice, and implementation. The first phase, creativity, is an inquiry phase where issues are surfaced from a range of stakeholders. Through system metaphors and other creative thinking tools these stakeholders share their understanding and perceptions on the problem situation (Jackson, 2003; Heyer, 2004; Molineux and Haslett, 2005).

The information from the "creative phase" is used in the "choice phase" to pick suitable methodologies. The "choice phase" employs the SOSM as a methodology selection framework to select one or a mix of methodologies. In cases where more than one methodology is required, a dominant and some dependent methodologies are selected for the main and secondary problem issues, respectively (Jackson, 2003). Through this "complementarism", TSI allows methodologies from different paradigms to be used within the same intervention (Clark, 2001). The task of the "implementation" phase is to use these methodologies to propose specific changes. Since the TSI employs SOSM, it also fails to separate techniques from methodologies. Jackson (1999: 16) states that TSI "stand above paradigms" and hence, pluralism under this approach is somehow "uncritical". Furthermore, Taket and White (2000) noted that there is insufficient attention given to the process of facilitation within the TSI (roles and styles that facilitators can adopt).

Multimethodology as specifically used in this review, will refer to the form where "methodologies are partitioned into components and then combined together to construct an *ad hoc* methodology" (Mingers and Broklesby, 1997: 492). This form of multimethodology promotes an even richer understanding of the complex world. Since the research/intervention process itself proceeds through a number of phases, multimethodology provides a comprehensive option by utilising different tools at relevant phases. This ability, even when the toools cover similar functions, provides some triangulation. Triangulation, state Gil-Garcia and Pardo (2006), is considered a key motivation for multimethodology because data and results are validated, providing more confidence to the research/intervention.

The main criticism towards multimethodology concerns paradigm incommensurability (Mingers and Brocklesby, 1997; Jackson, 1991; Flood and Jackson, 1991). The term "incommensurate", as defined by Oberheim and Hoyningen-Huene (1997), means "no common measure" and paradigms are considered incommensurate if they are "mutually unintelligible" (Hovorka, 2010).The issue of paradigm incommensurability, largely based on Kuhn's history of science (Kuhn, 1962), has been challenged by various authors (see Weaver and Gioia, 1994 and Gioia and Pitre, 1990). Kuhn's (1962) assertion was that paradigms generally succeeded each other and therefore, reconciliation between the "old" and the "new" was not possible (Andrew, 2001). According to Sankey (1993) later on Kuhn acknowledges that paradigms are not entirely incommensurable, but are partly, and that there is some overlap between paradigms. However, the question is: "where does incommensurability ends and commensurability begin?"

Flood (1990) and Jackson (1991) used Habermas (1972) theory of knowledge-constitutive interests (KCI) as a foundation to challenge paradigm incommensurability. The Habermas (1972) KCI theory states that all knowledge is aimed at serving three human interests *viz.* technical, practical, and emancipatory. Jackson (1991) argues that these interests are aligned with the hard, soft, and critical paradigms, respectively and as a result, paradigms are complimentary.

Flood (1990) and Jackson's (1991) work, however, have been widely criticised (see Midgley, 1996; Mingers, 1997; Spaul, 1997). Midgley (1997) as quoted by Andrew (2001: 113) dismisses Flood (1990) and Jackson's (1991) view as "standing above and beyond the paradigm debate". According to Midgley (1997) any attempt towards a "meta-paradigm" makes new paradigmatic assumptions. To overcome paradigm incommensurability and to provide a basis for the "new paradigmatic assumptions", Midgley (1997) appeals to Habermas's (1984) theory of communicative action. Habermas (1984) asserts that in any act of communication there are four validity claims *viz.* intelligibility, truthfulness (external world), justification (social world), and sincerity (internal world). In practice the three "worlds" are seamless although they are viewed as separate (Midgley, 1997). Midgley (1997) argues that the Habermas (1984) theory justifies multi-paradigm complimentarily because the hard, soft, and critical paradigms pursue the external, social, and internal "worlds", respectively.

Based on their (paradigms) assumptions, theories, and methods, Mingers (2001b) argues that there is no universal classification of paradigms and hence, the concept is just simply a heuristic. Mingers (2003a) surfaces the difference between Kuhn's (1970) "revolutionary paradigm" philosophy and Burrell and Morgan's (1979) philosophy of "antithetical paradigms" where paradigms exist simultaneously. From this Mingers (2001b: 243) believes that techniques and methodologies from one paradigm can be "critically and knowledgeably" detached and used within a situation that makes different philosophical assumptions.

Cultural and cognitive feasibility have also been raised as concerns towards the development and adoption of multimethodology (Brocklesby, 1995; Mingers and Brocklesby, 1997; Jackson, 1999; Mingers, 2001b). Cultural feasibility refers to the extent to which existing paradigm subcultures facilitate or act against adoption. Mingers and Brocklesby (1997: 499) noted that crossing and/or combining paradigms might require individuals to overcome "socially constructed obstacles", especially, those that have been trained and socialised in other paradigms. According to Mingers and Brocklesby (1997: 499) there is"*prima facie*" evidence that there are links between personality traits, entrenched cognition, and research preferences. Mingers (2001b) noted that certain personality types would have varying research preferences. It is this links, discussed by Mingers (2001b) in detail, that may cause people to "experience some difficulties in moving from one paradigm to another, and/or experience a certain internal tension or discomfort" if compelled to work outside their cognitive space (Mingers and Brocklesby, 1997: 499).

There are commonly two approaches to multimethodology: (a) the Mingers and Brocklesby (1997) approach also referred to as the M-B framework and, (b) the Mingers (2003a) approach. The Mingers and Brocklesby framework uses a 2-dimensional grid to map different tools, based on a classification of their relative strengths (Table 2.1). One side of the grid is based on Habermas's theory of communicative action (Habermas, 1979; 1984), and the other, Bhaskar's (1979) general phases of research and intervention (Mingers, 2003b). The Habermas theory "views" the problem domain along the three "worldviews" (material/external world, personal/internal, and social) and for that reason, outlines the multidimensionality in the real world. A material world deals with the actual and possible state of affairs, aspects that are hard and observer-independent (Mingers, 2010). The social world, on the other hand, focuses on the regulated social relations and interactions (Mingers, 2003b). Individual aspects such as beliefs, values, fears, and emotions are captured in the "personal world".

Bhaskar's (1979) general phases of research and intervention, as defined in Mingers (2003b) are; appreciation, analysis, assessing, and implementation. The "appreciation phase" tries to understand the problem situation as experienced by practitioners and expressed by participants, and literature reviews. It is a design and conceptualisation phase (Mingers, 2010) where methods such as observation, interviews, experiments, surveys, and/or qualitative approaches, among others, are used to understand the situation. The "analysis phase" interprets and examines information produced from the "appreciation" phase and use tools to understand and explain the underlying structures and constraints that maintain the problem situation. This includes analytic methods that are appropriate to the goal(s) of the intervention (Mingers, 2001a). The "assessment phase" weigh-up postulated explanation(s) and potential changes to the situation whilst the "action phase" is aimed at bringing about changes if necessary, or to report and disseminate findings (Mingers, 2010).

Table 2.1: The M-B framework for mapping interventions and methodologies (Mingers, 2001a; Davies et *al*., 2004)

	Appreciation of	**Analysis of**	**Assessment of**	**Actions to**
Social world	Roles, norms, social practices, culture and power relations	Underlying social structures, distortions, conflicts of interest	Ways of changing existing practices and culture	Generate enlightenment of social situation and empowerment
Personal world	Individual beliefs, meanings, values, and emotions	Differing Weltanschauugen and personal rationalities	Alternative conceptualisations and constructions	Generate understanding, personal learning and accommodation of views
Material world	Material, physical processes and arrangements	Underlying causal structures	Alternative physical and structural arrangements	Select and implement best alternatives

The M-B framework however, is subjective and *ad hoc* (Mingers, 2003a). The approach is more general towards the problem content, rather than being specific. To overcome these limitations Mingers (2003a) came up with another framework with additional dimensions. More than the comparison between methodologies, the Mingers (2003a) framework outlines the purpose of the intended intervention and also surfaces the philosophical assumptions underpinning each methodology and/or method under consideration. The framework classifies methodologies along seven characteristics which are then synthesised into a SSM root definition form (Checkland and Poulter, 2006). Root definitions are structured, condensed statements describing a system (Marijamdotter, 1998). The root definition recommended by Mingers (2003a: 562) takes the form of:

"A system to do the process specified, by developing models of that assumed to exist, in the specified form of representation, based on necessary information, gained from particular sources, in order to assist users achieve specified purposes."

3. TOOLS

This section discusses certain root cause analysis tools and systemic diagnostic tools. Each tool's history, applications, strengths, and limitations are highlighted. The review does not represent an exhaustive list but rather focus on tools which the author found to be applicable within an agri-industrial context. These tools include SYSTEM DYNAMICS, TOTAL QUALITY MANAGEMENT, VALUE STREAM MAPPING, THEORY OF CONSTRAINTS, VIABLE SYSTEMS MODEL, SOFT SYSTEMS METHODOLOGY, SUPPLY CHAIN COLLABORATION INDEX, FUZZY COGNITIVE MAPPING, and SOCIAL NETWORK ANALYSIS.

3.1 System Dynamics

System dynamics, an approach developed by Jay Forrester in the mid 1950's (Breistrand 2006), is used for studying and managing complex dynamic problems (Leonard and Beer, 1994). It is an interdisciplinary methodology grounded on the theory of nonlinear dynamics and feedback control (Sterman, 2001). The methodology identifies how interrelationships affect a system as a whole in terms of stocks and flows, and feedback loops (Ozbayrak *et al*., 2007). System dynamics is widely used in analysing physical, information, and financial flow (Angerhoffer and Angelides, 2000). This section reviews three system dynamics tools *viz*. causal loop diagrams, stock and flow diagrams and, system archetypes.

3.1.1 Causal loop diagrams (CLDs)

Causal loop diagrams are used as conceptual tools to capture and develop causal hypotheses (Chaerul *et al*., 2007). They can also be used to simplify a model's representation (Georgiadis *et al*., 2005). These loops, among others, capture mental models (for different individuals or teams) and are used to represent and communicate feedback (Lane 2000). Kiani *et al*. (2009: 163) state that a CLD "doesn't tell you what will happen, rather, it tells you what would happen if the variable were to change". A CLD consists of variables connected by causal links (arrows). These arrows have either a positive (+) or negative (-) polarity, which indicates the direction of causality between variables when all the other variables are conceptually constant (Koca and Sverdrup, 2012). The polarity in such cases indicates what happen to a dependent variable due to changes in independent variables, and as such, polarity describes the system structure and not the behaviour of the variables (Breistrand, 2006). A positive link, as stated in van Vliet *et al*. (2007) shows that an increase in the cause would increase the effect to above what it would otherwise have been, and if the cause decreases, the effect also decreases below what it would otherwise have been. For example, as seen in Figure 3.1, a longer lead-time will lead to a decrease in customer satisfaction and hence, customer orders.

When the causal links close (in a circular fashion) feedback loops are formed. The overall polarity of a feedback loop is usually indicated by a symbol in its centre (Koca and Sverdrup, 2012). There are two types of loops, positive (self-reinforcing) and negative (self-correcting or balancing) loops (Sterman, 2001). Positive loops are denoted by (+) or ***R*** and negative loops by (-) or ***B***. According to Georgiadis *et al*. (2005) negative feedback loops exhibits a goal-seeking behaviour after a disturbance, whilst positive loops reinforce or amplify whatever is happening in the system. Reinforcing loops create exponential growth or collapse, and if they produce a desirable result they are referred to as a virtuous cycle whilst if undesirable, a viscous cycle. The net effect of the individual links determines the type of loop and this is obtained by multiplying the signs of these links (Wolstenholme, 1994). Therefore, a balancing loop contains an odd number of negative causal links whereas a reinforcing loop has an even number (Chaerul *et al*., 2008).

Causal loop diagrams can be used as a workshop tool as demonstrated by Koca and Sverdrup (2012) who used CLD's within groups to analyse the impacts of potential climate change on natural ecosystems and socio-economic sectors. Causal loop diagrams can also be drawn from data collected through interviews as done by Soo (2005).

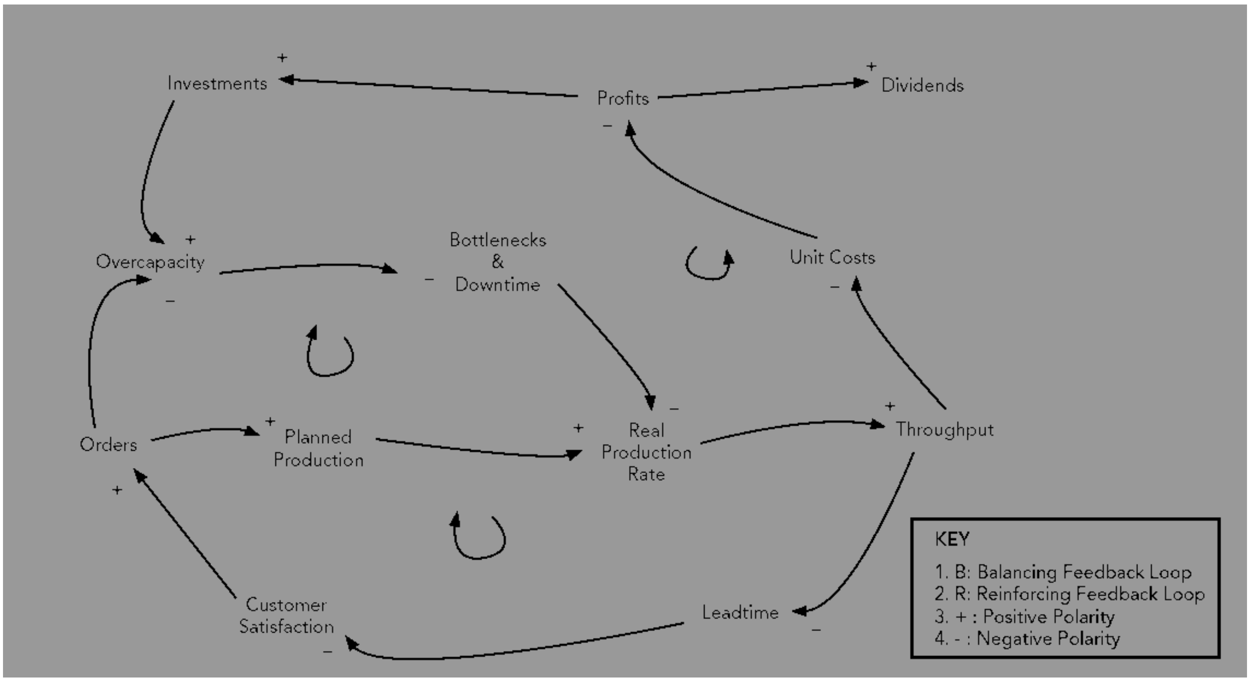

Figure 3.1: An example of a CLD (Uribe, 2008)

Some of the known limitations of CLDs are: inability to capture stock and flow structures (Zhang and Dilts, 2004), a lack of precision at the conceptualisation stage where behaviour is inferred (Lane, 2000), and poor loop polarity determination (Zlatanovic, 2012).

3.1.2 Stock and flow diagrams (SFDs)

A stock and flow diagram is a graphical tool that represents the model structure and interrelationships between variables (Georgiadis *et al*., 2005). Unlike CLDs, SFDs distinguish between the different types of variables. Stocks, also known as state variables or levels, define the state of the system over time and represent the major accumulations, whilst flow variables (derivatives) indicate the rate of change in stock (Zhang and Dilts, 2004). According to Sterman (2000) stocks are a source of disequilibrium due to delays in a system. Kirkwood (1998) gives six types of stocks in business *viz*. material, personnel, capital equipment, orders, and money.

Flows (indicated by double arrows in Figure 3.2) indicate activities that fill or drain the stocks. SFDs also have valves that symbolize the processes that control the flows and clouds that show the sources and sinks of flows. Converters or auxiliary variables (circles), as shown in Figure 3.2, store system information that affects flows or other converters and are used for miscellaneous calculations (Chaerul *et al.*, 2008). Finally, connectors (single arrows) link information between elements and represent the cause and effects within the model structure.

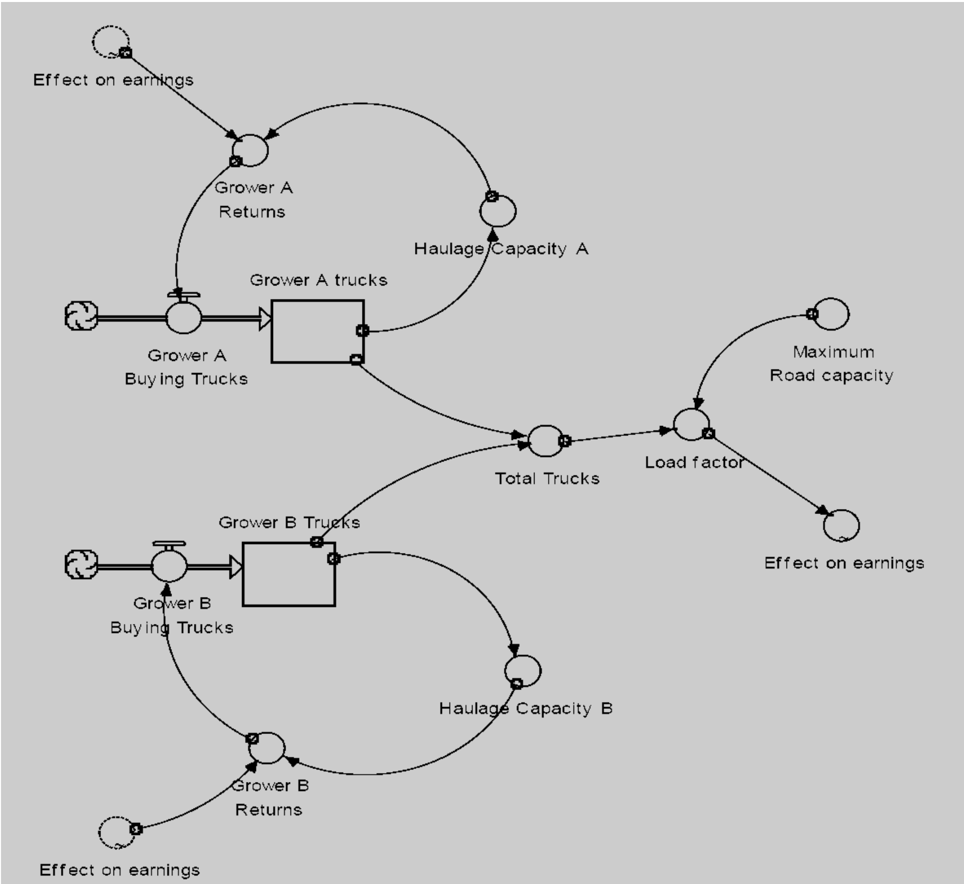

Figure 3.2: An example of the basic elements of a SFD (Bodhanya, 2011)

Figure 3.2 shows a SFD of two 'identical' growers who each invest in trucks to increase their respective haulage capacities. The stock in this case is the number of trucks and as each grower increases the number of trucks there is a corresponding increase in returns (Bodhanya, 2011). Earlier steps in SFDs construction is to identify the critical stocks, determine the flows, and defining converters. According to Binder *et al*. (2004) SFDs can also be constructed by transforming CLDs following a procedure outlined by Burns (2001). Kibira *et al*. (2010) used CLDs and SFDs to model and understand the structure of the corn-ethanol industry in USA. Due to excessive detailing and their technical orientation, Zlatanovic (2012) states that SFDs can be too complex to understand. If used for conceptualisation, SFDs lack the diagrammatic rigour of explaining all the dynamic phenomena and thus, sometimes lead to system behaviour being inferred.

3.1.3 System archetypes (SA)

System archetypes are an abstract of feedback structures used to describe underlying patterns of system behaviour (Braun, 2002; Wolstenholme, 2004). These patterns indicate the system structure and associated problems and mental models (Levine and Novak, 2008). System archetypes are sometimes referred to as basic stories or generic structures (ISEE Systems, 2006). Rather than focusing on individual factors or events, SAs consist of two or more causal loops. These archetypes mostly occur in combinations of reinforcing and balancing feedback (Goodman, 1994). According to Gillies and Maliapen (2008) system archetypes basically try to answer the "why do we keep seeing the same problems recur over time" question in systems.

System archetypes are used as prospective tools where they predict potential effect of policies on organisational structure (Braun, 2002). Through this function, SAs help organisations to avoid future counter-productive behaviour by structuring future strategies (Wolstenholme, 1993; Levine and Novak, 2008). In addition, SAs also recognise failure patterns as they develop and can be used to find interventions that can break on-going system dynamics (Levine and Novak, 2008).

There are three basic SAs as shown in Goodman's (1994) archetype family tree *viz.* fixes-that-fail, shifting-the-burden and limits-to-growth. The shifting-the-burden archetype usually begins with problem symptoms that prompt an intervention (Braun, 2002). To overcome these "challenges" symptomatic solutions are usually implemented as these are "obvious and immediate" (West, 2004: 28). These "quick fixes" however, "divert attention away from the fundamental sources of the problem and cause the viability of the fundamental solution to deteriorate over time (Kim, 1999a: 129). As a result, these symptomatic solutions become institutionalised, reinforcing the perceived need for more of the same. In a limit-to-growth archetype a reinforcing system performance that increases with an increase in a certain effort encounters a balancing process and, depending on the strength of the limiting condition, the performance levels off or fall (Kim, 1999a; Goodman, 1995; Braun, 2002). All of a sudden, an increase in the effort does not translate to improvements in the system.

As with the shifting-the-burden archetype, fixes-that-fail archetypes are also characterised by temporary, "quick fix" solutions. Unfortunately these fixes "triggers unintended consequences that make the original symptom reappear after some delay, often worse than before" (Kim, 1999b: 2). Other "secondary" SAs as discussed in Braun (2002) are drifting-goals, escalation, tragedy-of-the-commons, growth-and-underinvestment, accidental-adversaries and attractiveness-principle.

For data capture and conceptualisation Kim and Burchill (1992) used interviews in their study on the development of a structured process for mapping organizational change while focus group discussions were however, preferred in a healthcare system study by Gillies and Maliapen (2008). The conceptualisation stage involves mess definition, simplifying the mess, and explaining the mess (Kim and Burchill, 1992). Kim and Lannon-Kim (1994) suggest a six step investigative sequence that includes both data capture and conceptualisation. The generic nature of SAs makes it difficult to explicitly reveal important organisational variables (Braun 2002; Gillies and Maliapen, 2008) and as such, system archetypes should be applied with caution as they are rarely sufficient models.

3.2 Total Quality Management (TQM)

Total quality management is an "integrative management philosophy" aimed at continuous improvement of products and processes (Ahire, 1997: 93). To achieve this "continuous improvement", Burke (2007) states that TQM integrates all quality management components. These components, according to Klefsjo *et al*. (2006) are organisational core values, techniques and tools. Deming (1994) views TQM as a network of components that work together to meet the system's aims through techniques and tools. According to Andersson *et al.* (2006) the most frequently used tools in TQM are the seven quality control tools (Ishikawa, 1985) and the seven management tools (Mizuno, 1988). The management tools are the cause-and-effect analysis tools *viz*. affinity diagram, cause-and-effect diagram, interrelationship diagram, matrix diagram and prioritisation matrices. The next section reviews the cause-and-effect diagram, interrelationship diagram, and the affinity diagram.

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3.2.1 Cause-and-effect diagrams (CED)

The cause-and-effect diagram, also known as Ishikawa or Fishbone diagram (due to it structural outlook and appearance) was first developed by Kaoru Ishikawa in 1943 (Doggett, 2005). The tool is used in many fields to identify and group potential causes of effects or problems. Among its many applications CEDs have been used in the service industry (Hermens, 1997), aerospace (Skjei, 2005), and electronics industry (Seliger *et al.*, 2002; Muncy and Baldwin, 2004). The CED employs brainstorming to identify the potential causal factors. The main problem is usually written at the head of the 'fish' and the main causes as bones, and the smaller bones resemble sub-causes (Bose, 2012).

Andersen and Fagerhaug (2000) suggest a three-step procedure for data gathering and analysis when a cause-and-effect diagram is compiled: (a) the problem is written on the right end of the large arrow, (b) the main categories that may be causing 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 Arcaro (1997) the major categories should not exceed eight per diagram. To accomplish this Mahto and Kumar (2008) suggest the use of four M's in manufacturing cases and four P's for administrative and service sectors. Four M's represent manpower, methods, materials, and machinery. Furthermore, four P's stand for plant (equipment), policies, procedures, and people. Ishikawa (1990) classifies this into six categories namely: environment, equipment, material, management, people, and processes. Bose (2012) used two CEDs in a study at St James Hospital. The first CED was general and was based on Ishikawa's (1990) six categories. From the first CED, inefficient supply chain management was identified as the main problem, and this was the basis for analysis in a second CED where 5-why method was also used.

The simplicity of CEDs poses a problem as it becomes difficult to represent interrelated problems in complex situations (WBI Evaluation Group, 2007). This implies that individual

CEDs have to be drawn for each problem and the exercise becomes time-consuming (Bilsel and Lin, 2012). Furthermore, once completed CEDs do not have a specific mechanism for root cause identification (Zhu, 2010). This is because they do not differentiate between the strengths of different cause and effect relations (Doggett, 2005).

3.2.2 Interrelationship diagram (ID)

The interrelationship diagram is a quality tool that was first developed by the Society of Quality Control Technique Development in association with the Union of Japanese Scientists and Engineers in 1976 (Doggett, 2005). It is also referred to as a relations diagram or interrelationship diagraph. It is a structured cause-and-effect analysis tool used to identify root causes in complex problem areas. This, according to Brassard *et al*. (1994), is achieved by allowing stakeholders to identify, analyse, and classify cause-and-effect relationships that exist in a particular problem area. The tool graphically shows logical relationships between factors (Kolaric, 1995).

The ID is often used after cause-and-effect factors have been identified, mostly through brainstorming, CED, and/or affinity diagrams (see Section 3.2.3) (Department of Education and Children's Services, 2005). Interrelationship diagrams come in two forms: a quantitative format, and a qualitative format. With the qualitative format the elements to be analysed are simply connected and the root cause identification is through intuitive understanding. However, with the quantitative approach, root cause identification is based on a numeric value. Andersen and Fagerhaug (2000) outlined the following procedure when drawing quantitative IDs:

- Determine and label the elements to be analysed, write them on a board or flip chart (preferably arranged in a circular pattern).
- Identify the cause-and-effect relationships between factors and draw arrows to indicate the directions of influence (do not draw two-headed arrows).
- Tally the influence arrows (for each factor, record the number of arrows going in and arrows going out).

As a rule of thumb, the arrows point from cause to effect (Doggett, 2005; Zhu, 2010). Thus, factors with the most outgoing arrows are the root causes (drivers) and the elements with the most incoming arrows are the indicators (key outcomes or effects). Meier *et al*. (2004) utilised IDs after the use of affinity diagrams to illustrate relationship dependency from a buyer's perspective while evaluating potential suppliers. Leadership management, product information technology, and partnership capability were identified as root causes with 10, 8, and 7 out-arrows, respectively.

The ID's reliability on subjective judgements to identify factor relationships, however, makes it too complicated and hard to read (Andersen and Fagerhaug, 2000; Doggett, 2005). Furthermore, as stated in Doggett (2005), IDs do not have a mechanism to evaluate the integrity of the selected root causes.

3.2.3 Affinity diagrams

An affinity diagram is a qualitative group tool used to collect and organise language data (ideas, opinions, issues) associated with a particular problem. Affinity diagrams are also known as KJ diagrams, after Jiro Kawakita who first created them in the 1960's (Andersen and Fagerhaug, 2000). According to Judge and McCrickard (2008) the main use of affinity diagrams are to consolidate themes from user interviews or a brainstorming session into categories. It is more a creative thinking tool than a logical process (Anjard, 1995).

An affinity diagram is created from the bottom up, combining individual notes into thematic maps. The steps in the construction of affinity diagrams are as follows (Brassard, 1989; Kolaric, 1995; Andersen and Fagerhaug, 2000):

- Select the problem to be analysed and generate possible causes through brainstorming.
- Examine the ideas and cluster them into groups.
- The brainstorming group then discusses the final shape of the chart by reviewing the clusters and deciding on the best grouping.
- Clusters are given titles, dividing larger groups into sub-groups at lower levels and, a finished affinity diagram is drawn

Algozzine and Haselden (2003) used an affinity diagram in a classroom situation to classify and organise living things. The strength of an affinity diagram is its ability to sift through and organise large volumes of data and the fact that ideas are examined silently (encourages unconventional thinking and discourages semantic battles). However, affinity diagrams are not recommended for simple problems or where quick solutions are required i.e. if less than fifteen issues have been identified (Balanced Scorecard Institute, 1996).

3.3 Value Stream Mapping (VM)

Value stream mapping is a graphical tool, with its roots from the Toyota Production Systems (Lovelle, 2001), used to represent processes in a value stream (Chen *et al*., 2010). A value stream, state Braglia *et al*. (2006), is a collection of a firm's activities that produce a product or a service. These activities can be in incidental work, value-added work, and/or waste (Monden, 1998).The VM tool was originally developed by Mike Rother and John Shook with collaboration from James Womack using the Toyota's information and material flow diagrams (Womack, 2006). According to Skjelstad *et al*. (2009) VM maps material and information that signal and control production.

Value stream mapping as a lean tool, maps both material and information flow separately, integrates and show linkages between these two and, show customer requirements (Khaswala and Irani, 2001; McManus *et al.,* 2002; Quesada and Buehlmann, 2011). Quesada and Buehlmann (2011) define lean thinking as a process focussed on increasing the value added to products and services by identifying, reducing, and/or eliminating waste. By applying lean concepts and techniques VM provides information about time-based performances such as process and lead times (Mahfouz *et al*., 2011). A value stream map also shows information on process availability and production scheduling methods (Quesada and Buehlmann, 2011).

The first step in value stream mapping is to select a product family and this is followed by the creation of a current state map (CSM) (Tapping *et al.,* 2002). The CSM is created by following the production process to identify tasks and flows, and then collecting data on resources, time, and quality for each section (Rother and Shook, 1999).The second step is to analyse the CSM to determine opportunities for improvement. This is achieved through the identification and analysis of value-adding processes and wastes.

The mapping process (CSM) starts downstream and work upstream so that processes linked directly to the customers are mapped first. The CSM depicts the current operations and show both value and non-value adding steps. The process is conducted through physically walking along the flow and recording what exactly happens (Rother and Shook, 1999) or through secondary data and interviews as shown by Seth *et al*. (2008). Mapping starts at door-to-door flow level and then zoom-in or out to map individual steps within a process or external streams (Rother and Shook, 1999). Material flow is drawn from left to right at the bottom half of the map whereas information flow is depicted at the top half of the map, drawn from right to left (see Figure 3.3).

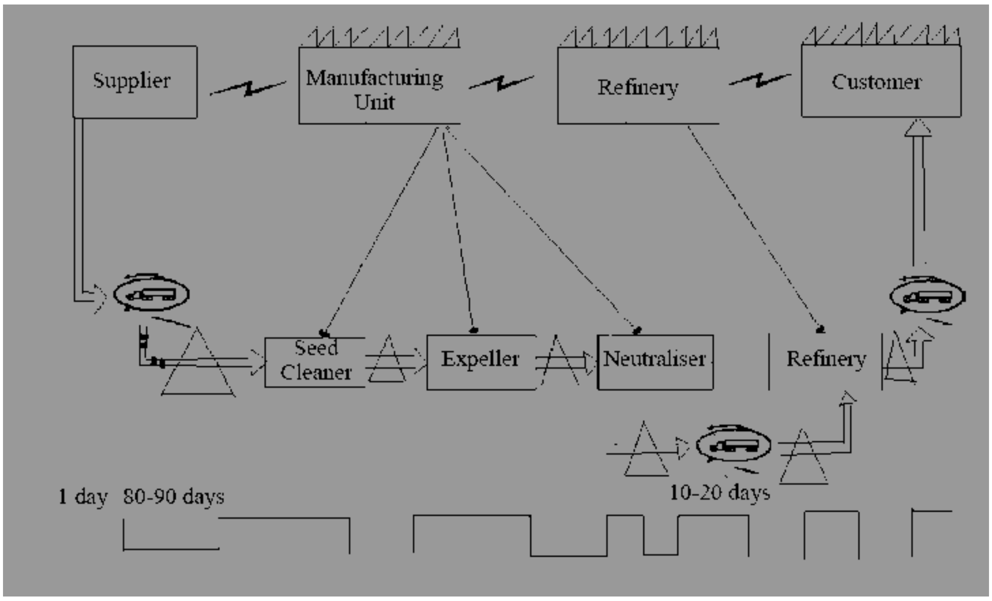

Figure 3.3: A current state map of a cottonseed processing supply chain (Seth *et al*., 2008)

The data collection procedure leads to different versions of the same stream and the map itself, hence, it might be too complicated for other stakeholders to understand (Lian and van Landeghem, 2002).Value stream mapping, as noted by Braglia *et al*. (2006) is effectively applied in linear systems and caution should be practiced if applied "as-is" in complex systems. To overcome some of these limitations, VM is widely integrated with other methods, for example Lian and van Landeghem (2002) used value stream mapping with system dynamics. Khaswala and Irani (2004) combined value stream mapping with production flow analysis and simplification toolkit.

3.4 Theory of Constraint (TOC)

The TOC is premised on the assumption that within any complex system there is a constraint, or a few, that limit system performance and that it is possible to identify such constraint(s) for improvement purposes. First developed by Eliyahu Goldratt in the late 1970's, the TOC is a continuous improvement tool that links both hard and soft systems (Gardiner *et al*., 1994; Mabin, 1999; Davies and Mabin, 2009). Although mostly used for business management, TOC is increasingly being used in social contexts, as well as in healthcare (Phipps, 1999; Breen *et al*., 2002). The TOC tool is made up of two different methodologies: a five-step methodology, and a strategic thinking process (TP). The five step methodology is used to analyse and structure physical constraints whilst the TP is used to identify non-physical constraints. The next section discusses a current reality tree, a TP tool used to answer the question, "what to change?" in continuous improvement.

3.4.1 Current reality tree (CRT)

A current reality tree depicts the state of reality as it exists in a system and attempts to answer the "what to change" question. It is a tool that searches for root causes to system problems (McNally, 2011) and explain how these (root causes) lead to the symptoms experienced (Davies *et al*., 2005). The latter is also known as undesirable effects (UDEs). According to Dettmer (1998) these root causes usually turn up to be the main constraints in the system. A CRT thus, identifies deviations, conflicts, and core problems as root causes (Scoggin *et al*., 2003). A core problem as stated by Dettmer (1997) is when a root cause is responsible for 70% or more of the UDE's in a CRT. A CRT thus, relates multiple factors rather than isolated events and is constructed from top-down by identifying observed UDE's and postulating probable causes for those effects (Mabin, 1999; Zhu, 2010). The UDE's identification is conducted through interviews (Walker and Cox, 2006), brainstorming, discussions, arguments, and debate with affected stakeholders (Davies *et al*., 2005).
According to Walker and Cox **(**2006) two approaches are used to build a CRT, *viz*. a traditional approach and a three cloud approach (Cox *et al*., 2003). The traditional approach as outlined by Fredendal *et al.* (2002) follows these steps:

- Compile a list of the UDEs; Noreen *et al*. (1995) suggest five to ten.

- Relate the UDE's through cause-and-effect.
- For each UDE explore a chain of possible cause-and-effect relationships responsible for their manifestation and identify the root causes.

As with most logic trees, the CRT can be used as a stand-alone tool, depending upon the nature of the questions under consideration (Matchar *et al.*, 2006). In such a case the CRT acts as a persuasion tool to persuade others to take a particular cause of action. Doggett (2005) also refers to communication CRT's, because they "logically and explicitly communicate the causal relationships of an existing situation" Cox *et al*. (1998: 26).

Choe and Herman (2004) used CRTs to find dissatisfaction root causes among employees. Twenty UDEs were identified from employees through group brainstorming sessions. A CRT was then constructed from the UDEs and from there three root causes were identified: (a) lack of efficient leadership, (b) unsupportive organizational structure, and (c) unclear job performance expectations. The complex nature of CRT building and its logic system, however, make CRTs difficult to grasp and time consuming (Doggett, 2005). Moreover, as stated by Button (2000), the application of CRTs can also be hindered if the root cause lies with bad management practices, as managers may not admit that a problem exists.

3.5 Viable System Model (VSM)

The viable system model, developed in the late 1960s by Stafford Beer (Reynolds and Holwell, 2010) is a blueprint for structural diagnosis and design in organizations. The model is an abstract combination of cybernetics and the laws of control (Snowdon and Kawalek, 2003; Mele *et al.*, 2010). It specifies structural preconditions for viability and is a helpful heuristic for organizational design, under the aspect of the "management of variety and the encouragement of self-organization" (Schwaninger and Rios, 2008: 153). Viability, as stated by Brocklesby and Cummings (1996), is the capability of an organisation to maintain an independent existence in the long term. According to Hoverstadt and Bowling (2002) the VSM represents organisation structure and key processes, communication, and information flows.

The viable system model assumes that any organisation is made up of (a) the environment, (b) the operations performed by the organisation in the environment (system 1), and (c) a meta-system (systems 2-5). It is the balance within these three components that gives the VSM its diagnostic essence. The VSM views organizations as recursive and Espejo and Gill (1997) state that recursive systems are based on the premise of self-organisation and self-regulation. As such, recursive structures are highly adaptive and are efficient generators and absorbers of complexity.

System One represents the operations function and is made up of several primary elements which interact with the environment while being controlled by management (Flood and Zambuni, 1990; Bustard *et al.*, 2006). System Two coordinates the activities of System One. System Three (Control) manages those activities of System One that "impinge upon one another or that can be coordinated for greater effectiveness" (Leonard, and Beer, 1994: 45). It provides synergy and cohesion (Bustard *et al.*, 2006). System 3* is an audit function which allows System Three to monitor and probe deeply into System One operations in specific areas. System Four (Intelligence) investigates the future, in contrast to System One which is concerned with the present environment (Beckford, 2002). It provides information about the organization's environment to investigate for future scenarios, and in the process reduces exposure to threats and scan for opportunities (Medina, 2006; Leonard, 2007). System Five provides a reference point for identity and strengthens coherence (Leonard, 2007). This function maintains the organization on a course that is consistent with its purpose, policy, and identity (Schuhmann, 2004; Bustard *et al.*, 2006).

Diagnosis follows an in-depth examination of the five VSM sub-systems, mapping the components against individuals, teams and/or departments (Walker, 2006; Kawalek and Wastell, 1999). To collect data Sudibyo (2011**)** used interviews and secondary sources whist Cezarino and Beltran (2009) relied on reports. The reality within organisations is then compared with the expectations of the model and remedies are suggested. However, VSM does not provide support on how to get from the "current reality" to the "desired state" (Schwaninger and Rios, 2008). Furthermore, given its theoretical foundation, the VSM, as stated in Walker (2006), is not an easy-to-use model and its application may encounter resistance in entrenched structures.

3.6 Soft Systems Methodology (SSM)

The Soft Systems Methodology (SSM) by Peter Checkland is a widely used soft approach (Rodriguez-Ulloa and Paucar-Caceres, 2005). It is used to unlock social complexity through the structuring and interpretation of messy problem situations (Gregory and Midgely, 2000; Checkland and Poulter, 2006). The methodology is interpretative in nature. The interpretative nature of SSM means that there are no definite or unique problem definitions, but perspectives. Soft systems methodology models therefore, do not describe the real world but generate "holonic ideal type" of human activity system's behaviour under a certain perspective (Lane and Oliva, 1998). The emphasis of SSM is not on finding out a solution to a specified problem, but rather gives an overview of the situation and identify both weaknesses and relationships (Patching, 1990). Soft systems methodology acknowledges system complexity and appreciates its inherent dynamicity (Presley and Meade, 2002). The methodology therefore, enhances collaboration, communication, and information sharing (Tavella and Hjortso, 2012).

Soft systems methodology have two versions *viz.* the mode 1, which is the original seven stage logic-based sequences as outlined by Checkland (1981), and mode 2, which is a two-strand version by Checkland and Scholes (1990). According to Jackson (2003) mode 1 seems to contribute to a systematic rather than systemic understanding of the problem area and appear cut-off from the organisational activities, hence the emergence of the two-strand approach. The Checkland and Scholes (1990) version is formulated as two parallel streams of inquiry; (a) cultural and (b) logic-based (Barnden and Darke, 2000). The next section reviews the mode 2 version and discusses its diagnostic tools *viz*. rich pictures and cultural analysis.

3.6.1 Rich pictures

Rich pictures are used to depict a deep representation of a problem situation in which an intervention is required. These describe, pictorially, the key elements of a problem situation (Tavella and Hjortso, 2012). Rich pictures probe and capture entities, structures, viewpoints, and processes in an informal manner (Lane and Oliva, 1998). According to Checkland and Poulter (2006) rich pictures help the facilitator to take a snapshot of the problem situation and improve communication with the problem owner. They harness complexity through the capture of emerging circumstances. Rich pictures can be drawn by the stakeholders and/or the facilitator in a participative workshop setting or can be drawn by the researcher during an interview with stakeholders (Kotiadis and Robinson, 2008). A variety of methods, as stated in Lester (2008: 2), are used to "enrich" rich pictures, from "formal research techniques to unstructured and serendipitous approaches". As a result, rich pictures convey both hard and soft information (Harry, 1994).

Various "relevant systems" are extracted from rich pictures and expanded into root definitions if one follows all the steps in the SSM logic-stream (Jackson, 2003). As noted by Lane and Oliva (1998), the drawing of rich pictures does not have a specific format or language and depends much on the skill and purposes of the person(s) doing the drawing. This characteristic, therefore, makes it difficult to interpret someone else's picture. Moreover, Sutrisna and Barrett (2007) recommend a set of standard symbols to apply in case of multi-case studies.

3.6.2 Cultural analysis

According to Checkland and Scholes (1990) cultural enquiry takes the form of (a) intervention inquiry, (b) social, and (c) political inquiry. The intervention enquiry, also known as Analysis 1, analyses the intervention in the problem situation, as a problem in itself, and explores the roles of client, practitioner, and the problem owner (Marijamdotter, 1998; Staker, 1999). A client is someone who commissions a study whilst a practitioner or problem-solver's role deals with the person(s) who is conducting the investigation or who "wishes to do something about the problem situation" (Kotiadis and Robinson, 2008: 954). The people concerned or affected by the intervention are the "problem owners". Checkland (1981) defines the problem owner's role as the person(s) taken by the investigator to be likely to gain most from any improvement in a problem situation or rather, those stakeholders with an interest in the problem. Jackson (2003) noted that in most cases there are basically no clearly defined problem owners and as such the net should be cast as wide as possible to ensure a rich source of perspectives.

Social inquiry, sometimes referred to as Analysis 2, examines the problem's history and social reality (Checkland and Poulter, 2006). It uses a simple dynamic model that assumes a system to be made up of dynamic interactions between three elements: roles, norms, and values. Roles, as stated by Checkland and Poulter (2006), are social positions recognised by people in a problem situation and can be formal (e.g. Head of Department, Senor Manager, Professors) or informal (e.g. Role Models, Mentors). Social norms are expectations that people have for the behaviour or patterns of action of those occupying roles thus, to a certain degree, norms define roles. In a social system the performance of norms is measured against values and values in this case are accepted standards or criteria by which "behaviour-in-role" is judged.

The political enquiry (Analysis 3) views the system from a political perspective and aims to analyse power disposition and the processes available for containing it. The political analysis is based on a theory of "accommodation" by Aristotle (Checkland and Poulter, 2006). This theory states that different interests are always at play in any society and therefore, to remain coherent, a system should ensure that these interests are accommodated. To determine the manner in which power is expressed in a problem situation, 'commodities of power' are first identified before investigations on how these are acquired, utilised, protected, preserved, transferred and relinquished are carried out.

Cultural analysis is continually updated and developed as the intervention proceeds, not just done once and stored. This analysis is incorporated into the rich pictures and also feeds into the other stages of analysis, informing actions that are culturally feasible (Reid *et al*., 1999; Jackson, 2003). Analysis 1, 2 and 3 complement each other, and can be undertaken in any order (Kotiadis and Robinson, 2008). However, Pidd (2007) advises that a certain amount of sensitivity should be observed when conducting social inquiry.

3.7 Supply Chain Collaboration Index (SCCI)

The SCCI is a collaboration diagnostic tool first proposed by Wilding and Humphries (2006). Supply chain collaboration, as stated in Soosay *et al*. (2008: 161), is an inter-organisational relationship where parties agree to "invest resources, mutually achieve goals, share information, resources, rewards and responsibilities as well as jointly make decisions and solve problems”. The SCCI captures qualitative and quantitative data and in the process reveal the dynamics of long-term collaborative relationships. The SCCI also provides metrics for performance measurement, monitoring, and continuous improvement.

The index is based on five supply chain relationship key performance measures from Williamson’s (1975) economic organisation failure framework; creativity, stability, communication, reliability, and value. It also measures seven other relationship attributes; long-term orientation, interdependence, C^3behaviour (being co-operation, co-ordination and collaboration), trust, commitment, adaptation, and personal relationships. Wilding and Humphries (2009) suggests this sequence when computing a SCCI:

- From each organisation, select at least two senior executive staff members who deal with collaboration issues.
- Design a questionnaire and collect data on key relationship characteristics. This should be completed by any knowledgeable staff, from “shop floor all the way to senior management”.
- Prepare and present the results from the questionnaire to the stakeholders (Barometer report).
- Conduct interviews on the nominated ‘collaboration staff’ and, a final report synthesising the findings of the questionnaire and the interviews is written.

A barometer report is made up of traffic lights, relationship overviews, and the industry rankings. Traffic lights express the strengths and weaknesses for each relationship characteristic as a percentage score as shown by Humphries and McComie (2010). Relationship overviews show perceptions of each firm on the other whilst industry ranking groups all the relationships assessed and assign a value. Bezuidenhout *et al*. (2012b) conducted interviews and held stakeholder workshops to determine the level of collaboration in three sugarcane milling areas in South Africa. During the interviews stakeholders were asked to rate their relationships with other parties using relationship maps and each of these relationships (from maps) were then evaluated according to the SCCI attributes.

3.8 Cognitive Mapping

Cognitive mapping is a tool used to evaluate the structure and content of cognitions. It is based on George Kelly's theory of constructs (Ackermann *et al.*, 1990). Cognitions are mental models that people use to perceive, interpret, contextualize, simplify, and make sense of complex problem situations (Tolman, 1948). According to Kelly's theory individuals achieve this by comparing and contrasting events and, through this they are able determine patterns and themes that help make sense of and manage future events (Ackermann *et al*., 1997). Faiweather (2010) points to the fact that cognitive maps indicate factors and causal relationships in-between whilst Swan and Newell (1994) believe that they also reveal factor similarity, proximity, category, and continuity. According to Mingers (2003a: 566) cognitive maps represent an "individual's beliefs about a situation, rather than a map of the situation itself".

Cognitive mapping techniques allow the examination of subjective beliefs by both the subject and others (e.g. individuals and groups) with an interest (Eden, 1992). Although often used on a one-on-one basis, cognitive mapping is also used with groups and at such, portrays those beliefs that are significantly held by stakeholders (Ackermann *et al*., 1990). Group maps are achieved through the merging of individual maps or in the sense of group model building, directly created by the group when using a facilitator in a brainstorm-type workshop (Eden, 2004).

3.8.1 Fuzzy cognitive mapping (FCM)

Fuzzy cognitive maps are signed digraphs **(**Dickerson and Kosko, 1994) first introduced by Kosko (1986) as an extension to cognitive maps. They are used to depict and analyse complex human perceptions (Papageorgiou, 2013). Fuzzy cognitive maps are a combination of fuzzy logic and neural networks (Stylios and Groumpos, 2000) and have been applied in a variety of areas such as decision-making in social systems (Cossette and Audet 1992), production systems (Lai *et al*., 2009), logistics (Bertolini and Bevilacqua, 2010), and ecology and environmental management (Kok, 2009; Isaac *et al*., 2009; van Vliet *et al*., 2010). They (FCMs) are based on textual descriptions given by domain experts. The approach involves

(Khan *et al*., 2000; Stach *et al*., 2005): (a) identification of key system variables, (b) identification of causal relationships between these variables, and (c) determining the strength of the causal relationship. Besides the graphic form, FCMs are also expressed mathematically as a vector matrix (adjacency or edge matrix).

Fuzzy cognitive maps are dynamic in nature and consist of concepts (trends, actions, events, values, or goals) and causal relations in-between. In a graphic form these concepts are represented as nodes C_{ij} and the causal flow relationships, edges or arcs W_{ij} . The edges express the type and degree of causality. These can be one of three possible types; either positive $W_{ij} > 0$, negative $W_{ij} < 0$ or no relationship $W_{ij} = 0$, where the value of W_{ij} indicates the strength of the relationship between concept C_i and concept C_j. Dickerson and Kosko (1994) state that FCMs can have W_{ij} in the set $-1, 0, 1$ and concept values in $0,1$, where for the concepts -1 reflects a strong negative impact, 0 no impact, and 1 a strong positive impact. A C_{ij} value of 1 indicates that the concept represented is present to the maximum degree (Papageorgiou and Kontogianni, 2012).

According to Xiang and Formica (2007) FCMs can be drawn from surveys, worksheets, pattern notes, and reports. If expressed in matrix form, different FCMs from different sources can be combined to form one FCM. The matrices are simply added up, element by element (Bechtel1, 997) and in case of deficient concepts, augmentation is exercised (insert zeros). Ozesmi and Ozesmi (2003) condensed thirty five maps from stakeholder workshops and individual interviews in a study to develop a participatory ecosystem management plan for the Uluabat Lake in Turkey. The individual maps were first transformed into adjacency matrices and then condensed as stated in Dickerson and Kosko (1994).

The manual development of FCMs can be difficult to carry out in complex systems with a multiple number of nodes, more especially because they require expert knowledge and knowledge of the FCM methodology as well, thus, computational methods are often used and these substitute the expert by relying on historical data (Stach *et al*., 2005).

3.9 Social Network Analysis (SNA)

Social network analysis is used to study relational and structural properties of social entities in terms of network theory (Streeter and Gillespie, 1992). Structural properties deal with the arrangements of social grouping i.e. individuals, groups, or organizations (Haythornthwaite, 1996). Relational properties, moreover, determines the nature and extent of these relationships, their patterns, and their implications (Martines-Lopez *et al*., 2009; Dube *et al*., 2011). The relational links, as stated in Wasserman and Faust (1994) can be undirected (edges) or directional (arcs). To achieve this, SNA uses techniques from graph theory (see FCM, section 3.8.1), algebra, and statistics (Mueller et *al*., 2008). Reffay and Martinez-Mones (2011) trace the roots of SNA back to Moreno (1934). Social network analysis has been widely used in collaboration studies (Cross *et al*., 2002) and innovation adoption studies (Midgley *et al*., 1992; Bandiera and Rasul, 2006). Network analyses integrate both qualitative and quantitative data (Collins *et al*., 2008) and can be applied in both hard and soft issues (Borgatti and Li, 2009). According to Belamy and Basole (2013) network analysis offers a bridge between technical and social issues.

Information is gathered through surveys (Cross *et al*., 2002) using questionnaires or interviews and/or records (Newman, 2003). Graph theory is applied to the links to determine relationships between individuals, detect singular nodes, and to identify properties of the network as a whole (Reffay and Martinez-Mones, 2011). An important attribute of SNA is finding actors that have a central position in a network or answering the question "who is the most important actor(s) in the network" (Mueller et *al*., 2008). From graph theory, centrality has three measures; degree, betweenness, and closeness (Koschutzki *et al*., 2005). The degree centrality D_c of a node is a measure of links that an actor has with other actors in a network and thus, is a measure of local centrality. A high node D_c reflects high connectivity. Closeness centrality C_c , however, is a measure of global centrality. It gives an estimate of how closely connected a node is to others in a network. Betweenness centrality is a measure of the brokerage of an actor and estimates the probability that the "shortest path between any pair of nodes of a network passes through a certain node" (Martines-Lopez *et al*., 2009: 111).

Bezuidenhout *et al*. (2012a) and Bezuidenhout *et al*. (2013) used SNA to identify system constraints in the South African sugarcane supply and processing system. Using logical relationships, connectivity between issues was established and networks were constructed (through Pajek Software) for each mill. Each network was energised using the Kamada and Kawai (1989) energy transformation to position related nodes into local proximity of each other. According to Bezuidenhout *et al*. (2013) researcher's perceptions introduce bias into SNA. In addition, Scott (1988) and Martinez-Lopez *et al.* (2009) noted that network size can be limitating as large volume data could be overwhelming for generic software. Results from SNA are a "snapshot taken during an evolution process" (Coulon, 2005: 5) and, state Bezuidenhout *et al*. (2013), should not be generalised as they are time-specific.

4. SYNTHESIS AND CONCLUSION

To understand the research and intervention dimension, Davies *et al*. (2005) compared the M-B framework with the Ackoff's process model (Ackoff, 1978) and Simon *et al*.'s conceptualisation of problem-solving and decision-making model (Simon *et al*., 1987). From this comparison it is shown that diagnostics fall under the "appreciation" and "analysis" phase of the M-B framework. Table 4.1 shows the tools discussed in Section 3 mapped against the "appreciation" and "analysis" phases in an M-B framework. A convention of shading is used to indicate the extent to which a tool supports a certain phase of intervention. The darker the shading (black), the stronger the support offered by that particular tool. Most of these tools operate within both phases, but tend to be more suitable in one than the other. However, tools such as FCM, SCCI, SNA and VM show a strong ability in both "appreciation" and "analysis phase". The "analysis phase" of both FCM and SNA uses network analysis, so these only differ at the "appreciation phase" (depending on their application). The SSM's rich pictures and cultural analysis are "appreciation" tools. Rich pictures are a good way to explore the material world whilst cultural analysis appreciates the socio- political dimension.

From Table 4.1, it can also be seen that strong analysis tools are cultural analysis, SCCI, FCM, rich pictures, SFDs and, VM. Although a strong "analysis" tool, group facilitation with SFDs is complicated, which this renders this tool unsuitable for workshop settings. However, as noted earlier, at the "analysis" phase SNA and FCM can be "combined" as they both utilise network analysis. The strong "analysis" tools therefore, as shown in Table 4.1 are VSM, SAs, VM, and "network analysis". Within Bezuidenhout *et al*.'s (2013) supply chain constructs the material world for example, will consist of biophysical, economics, and environment constructs and from Table 4.1 these can be diagnosed with rich pictures, VM, SAs, VSM, CRTs, and "network analysis".

Table 4.1: Tools "worldviews" based on the M-B framework (Mingers and Brockesby, 1997)

Tool	**Social**		**Personal**		**Material**	
	Appreciation	Analysis	Appreciation	Analysis	Appreciation	Analysis
¥CLD						
¥SFD						
*SA						
¥FCM						
VSM						
†Rich pictures						
*Cultural analysis						
†CRT						
*VM						
†ID						
¥SCCI						
¥SNA						
†CE Diagram						
†Affinity diagram						

† Brainstorming tool *Interview tool ¥Brainstorm and/or interview

As an "appreciation" tool, rich pictures have a potential to be applied in almost all the constructs, except for the cultural construct where cultural analysis is the sole tool. Cognitive mapping as another strong "appreciation" tool can be used to compliment the SSM rich pictures and cultural analysis as shown by Ormerod (1995). Rodriguez-Ulloa and Paucar-Caceres (2005) soft system dynamics methodology uses rich pictures, root definitions and causal loops. Rees (2000) used root definitions with CLDs and SFDs for cause-and-effect modelling. Kinloch *et al*. (2008) on the other hand, proposed a framework that combined SSM conceptual models with VSM's system 3, 4, and 5.

The data collection approach (s) forms a critical part of tool selection as the exercise (data collection) must be comprehensible, user-friendly, and non-exhaustive to the stakeholders. The use and combination of various tools in complex systems should represent its complex and dynamic nature. More than the fact that these tools, to a certain extent, overlap and/or substitute each other, it is their complementary nature that has given rise to multimethodogy.

Uncritical adoption and application of multimethodogy frameworks from different settings should be guarded against as every situation is different. Frameworks should therefore, be structured such that they are "a basis for dialogue and learning".

5. PROJECT PROPOSAL

5.1 Proposed Title of Research

"The development and evaluation of an integrated diagnostic toolkit for integrated sugarcane and processing systems"

5.2 Rationale

Innovation is a valuable asset that gives supply chains a competitive edge (Wu and Chen, 2006). However, the adoption of innovative research recommendations in agricultural value chains (McCown, 2002) and the sugarcane supply and processing chain in particular (Bezuidenhout and Baier, 2011), has been relatively slow when compared with other industries such as electronics and automotive (Bezuidenhout and Bodhanya, 2010). Higgins *et al*. (2010) blame this perceived "failure" on the history of traditional Operations Research (OR) within the *agri-industria*. Traditionally, OR promotes system sub-optimisation and, as stated in Jackson (1991: 78), it is "associated with a limited range of mathematical techniques". These mathematical models have been identified by Bezuidenhout and Baier (2011) as a popular system improvement technique within sugarcane supply and processing systems (SSPS). Gerwel *et al*. (2011: 177) noted an emphasis on technical and hard issues such as "cane quality and supply, mill efficiency, and division of proceeds" within the South African SSPS. Sub-optimisation, moreover, creates problems in systems such as agricultural value chains where there are complex interacting drivers. It also violates modern supply chain thinking where systems compete as a whole (Christopher, 2005). According to Bezuidenhout and Bodhanya (2010: 28) SSPS are dominated by long-term focused research aimed at making "large and permanent" system changes. Nonetheless, Bezuidenhout and Baier (2011) advocate for short-term focused *in situ* opportunistic solutions with an aim of making small, incremental changes. These authors (Bezuidenhout and Baier, 2011) noted the vast application of this approach in the field of medicine especially, pharmaceuticals and therapy.

As characterised by a large number of autonomous stakeholders, the SSPS faces the existence of diverse mental models, goals, values, expectations and strategies (Bodhanya, 2011; Gerwel *et al*., 2011). This, as in other complex systems, collectively exhibit emergence and behaviour that "cannot be explained by merely studying the individual" (Bezuidenhout *et al*., 2013: 10). A systems thinking approach is required to improve the performance of the SASSP, as advocated by Holmberg (2000). This calls for the knowledge of the overall health of the system before any successful changes can take place (Basnet and Childerhouse, 2003; Bezuidenhout and Bodhanya, 2010). The diagnostic stage, noted Salama *et al*. (2009), is at the 'heart' of any system improvement. According to Grey *et al*. (2003), poor diagnostics are a major constraint to continuous improvement. However, diagnostics can be more challenging, especially in complex systems, than generating a solution (Rosenhead and Mingers, 2001). The SSPS is a socio-technical system (Behdani, 2012) and therefore, does not fit into a single systems thinking paradigm. Any effort towards diagnosis as a result, must address both hard and soft paradigms simultaneously (Basnet and Childerhouse, 2003; Bezuidenhout and Baier, 2011). The inquiry should cover physical, technological, socio-technical, managerial and behavioural components (Gerwel *et al*., 2011). According to Bezuidenhout and Baier (2011) any intervention in the SASSP should consider five supply chain flows *viz*. material handling, information chain, innovation, collaboration, and value chain. However, later on, Bezuidenhout *et al*. (2013) noted that these were "incomplete" and proposed a ten-domain system; biophysical, collaboration, culture, economics, environment, future strategy, history, information sharing, political forces, and rules, laws and structures. A summary of the underpinning principles of the toolbox is shown in Table 5.1.

Table 5.1: Principles that underpin the integrated sugarcane supply and processing system diagnostic toolbox

The framework must be systemic in nature
The framework must combine the strengths of the various existing soft and hard tools to structure and diagnose complex problems
It must be able to identify and diagnose any supply chain dimension or a combinations thereof, *in situ*

5.3 Research Question

What are the currently available systemic supply chain diagnostic tools and how can these tools be collectively used to diagnose and make sense of problems and issues in SSPS as a basis for continuous improvement?

5.4 Aim

In line with the continuous improvement philosophy of incremental changes (Bhuiyan and Baghel, 2005), this study seeks to develop and test a novice overarching heuristic for the integrated SSPS that will diagnose relatively small, but pertinent, system constraints and opportunities. The heuristic will only be diagnostic; implementation of its findings is outside the scope of this research. To the researcher's knowledge, this will be the first comprehensive integrated supply and processing systems diagnostics toolbox in any agricultural supply chain in the world. The knowledge gained in this study will be transferable to many other industries, including the large number of new and rapidly developing bio-fuel and bio-refinery supply systems.

5.5 Specific Objectives

The specific objectives of the project are as follows:

- To conduct a literature review on multimethodology and system tools that are currently used to diagnose supply chain problems in a wide range of industries, especially, *agri-industria*.
- To develop and demonstrate a suite of complimenting tools that would assist in establishing an in-depth understanding of the complexities at a cane supply area in terms of the many dimensions that govern the system, such as culture, history, political forces, information sharing, environment, future strategy, biophysical, and economics, and rules, law and structures.
- To demonstrate the heuristic by conducting a case study in a cane supply area.

- To make recommendations on systemic problem identification philosophy within the integrated SSPS.

5.6 Methodological Approach

The heuristic will adopt a "therapies path" type of diagnosis (Salama *et al.*, 2009). This starts with the identification of symptoms before these (symptoms) are examined through causal relationships to arrive at root causes. A thorough literature review on systemic diagnostic tools will form a basis for the development of the heuristic. Tools will be drawn from other systems analyses fields, such as finance, business, and medicine. Following a multi-method approach, the M-B framework (Table 2.1) will be employed to select and link tools based on their relative strength towards addressing the ten supply chain dimensions. The heuristic will be evaluated by means of a case study at Mhlume sugar milling area, Swaziland. An inquiry phase will first be conducted through interviews on a wide range of stakeholders (growers, hauliers, and those involved in mill operations). The output from the interviews will determine the tool(s) that will be used for further diagnostics to obtain a rich understanding of the milling area and its constraints. The case study will be explorative in nature and will involve a continual monitoring process of "reflection and design" (Mingers, 2001a). As information is revealed, additional tools from the toolbox will be employed to help engage with the exposed issues. For example, if collaboration is revealed as a problem area during the preliminary survey then the SCCI might be carried out in addition to further help uncover the essential issues. The final outcome will be a rich description of the issues at the mill area which should provide a good foundation for system improvement. The whole data collection pack will include a confidentiality statement on the part of the researcher(s).

5.7 Resources Required

The study falls under the general ethical clearance that was obtained in 2010 for large multi-mill supply chain surveys. The project is largely self-funded with some support from the School of Engineering. Resources required are as shown in Table 5.2.

Table 5.2: Resources required for the project

Resource	**Purpose**
Accommodation	During data collection
Vehicle	Local and cross-border to Swaziland (data collection)
Audio recorders	Audio recording during data collection
Telephone	Communication
Air tickets	International and some local conference travels

5.8 Work Plan

The proposed work plan is shown in Table 5.3.

Table 5.3: Workplan

Task	**2013**						**2014**												**2015**				
	J	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**
Literature Review	■	■	■	■	■	■	■	■															
Development of heuristic	■																						
Data collection			■	■	■	■																	
Data analysis				■	■	■	■	■															
Journal articles and Conferences	■	■	■	■	■	■			■	■	■	■											
Final draft submission													■	■									
Final thesis submission																					■	■	■

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