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Systems of Systems: Pure, and Applied to Lean Six Sigma

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1. Introduction

This chapter will briefly introduce the principles of General Systems Thinking (GST) as defined by classic literature on the subject (Ackoff, 1971; Battista, 1977; Bertalanffy, 1968; Boulding, 1956; Churchman, 1968; Waelchi, 1992; Weinburg, 1975). In particular, this chapter will contrast two opposing operational research (OR) views about systems thinking; the 'reductionistic' ('hard') approach and the 'holistic' ('soft systems methodology') approach. This chapter will then focus on the later; holistic soft systems methodology (SSM), which is the most suitable approach for improving human activity systems, rather than hard systems thinking which is more suitable for mechanistic or physical systems.

SSM may be used for such activities as organisational understanding, process improvement, strategy deployment and change implementation – which are all part of Lean and Six Sigma. A specific type of soft systems thinking will be majored upon, known as Process Orientated Holonic (PrOH) Modelling (Clegg, 2007), which will be used to show how holistic systems thinking can be used to improve organisational performance. The main differentiation between this methodology and any other SSM is that it allows for 'emergent properties' and 'hidden properties' of a system of systems to be depicted by using its unique way of defining a system of systems through the dimensions of 'pitch', 'width' and 'length' (from 'pick-up point' to 'drop-off point'); its abstraction and enrichment rules; the use of holons and holarchies, natural language, story boarding and colourful diagrams.

The case study given in this chapter focuses upon contemporary business improvement trends known as 'lean management' and 'six sigma'. Lean management attempts to reduce waste in an organisation, and six sigma improvement attempts to reduce variation in a process outputs. In reality there is a need to do both, particularly in these challenging economic times. Both lean management and six sigma improvement should be systemic, but this is rarely recognised and even less seldom practiced. The combined technique known as 'Lean Six Sigma' (LSS) is emerging as an attempt to fuse the two approaches together. However a clear concise model has not yet been produced (Pepper and Spedding, 2010). Thus, the current challenge is to produce a unified model of lean management and six sigma improvement that is systematic, systemic and holistic which can be used to optimize systems as a whole. The danger of not applying system of systems thinking to lean management and six sigma improvement initiatives is that different levels (or pitches) of thinking (e.g. philosophy, methodology and tools) and their potential overlap will go unrecognized; and thus their potential impact on organizational performance will be reduced.

This chapter will include discussion about both 'pure' GST and system of systems *per se,* particularly the 'soft' variety which will be of interest to philosophically motivated audiences, such as academic researchers. It will also include 'applied' systems thinking, using PrOH Modelling which will interest audiences wishing to use system of systems thinking to improve 'real world' lean-six sigma systems.

2. Philosophical background to systems thinking

Systems thinking has developed into a discipline in its own right with applicability to almost any area because of its generality (Jackson, 1995). In particular, GST has been applied in the area of scientific management (hard systems methodologies) and more recently to the organizational and human elements (soft systems methodologies). In particular, soft systems thinking has been successful because of its capacity to consider complex situations with competing goals, such as efficiency and quality. Consequently, different types of soft systems thinking have arisen with subtly different purposes; for instance Checkland's Soft Systems Modelling (SSM) is used for general problem definition (Checkland, 1988), Viable Systems Modelling (VSM) to 'diagnose' the operational effectiveness of an existing system and propose their redesign (Beer, 1985), and PrOH Modelling, specifically to improve organisational processes (Clegg, 2007).

GST aims to describe systems with an optimal degree of generality, between the highly generalized relationships of mathematics and the specific theories of the specialized disciplines. Thereby different bodies of knowledge can be combined theoretically into "a body of theoretical constructs which discusses the general relationships of the empirical world" (Boulding, 1956). However it is often difficult for modellers to observe systems as a whole thus systems are not objectively 'real' but subjective; being perceived and inferred by individuals representing what man has created to manage aspects of the world through historical and evolutionary adaptation (von Bertalanffy, 1968). This is particularly the case in behavioural and social systems; in these situations GST represents a method of combining knowledge into a 'system of systems' to act as a 'gestalt' entity (German: essence or shape of an entity's complete form) for theoretical construction. Thus GST can be utilized to organize a large body of information in a way that can identify previously unobserved interrelations; however the subjective nature of systems makes it difficult to prove or refute models developed using GST. Because of such subjectivity it is essential to be clear on ones definition of system of systems. Hence the authors define a system by its constituents and contingency; specifically, people machines, critical success factors, inter-relationships, boundary, inputs, outputs, controls, name and environment. Therefore a system of systems is an entity that is defined by its respective constituents and contingencies *and which may contain other systems and may itself be part of a larger system.* (Churchman, 1968; Ackoff, 1995, 2006).

Boulding (1956) highlighted the need to move away from "mechanical models" that rely on simple, mathematical approaches to better understand the functioning of the World. He utilizes the system of systems approach to GST to arrange "theoretical systems in a hierarchy of complexity" (Boulding, 1956 pp. 202) from level 1, representing simple systems and a low level of understanding, to level 9, representing complex systems and a high level of understanding. He argues that most understanding is at 'level 1' (static structure) or 'level

2′, (simple dynamic system) with some disciplines attaining 'level 4′, (open system or self-managing structure). Social organizations at 'level 8′ exhibit their own characteristics in addition to those of their subsystems, levels 1-7. However the characteristics of a social organization cannot be explained by its decomposition into its constituent parts rather its characteristics emerge from their interaction (Ackoff, 1995). Ackoff (1995) develops the 'system of systems' concept by defining the elements of a system and the changes that occur within them. In this context it is reasonable to suggest that over time an organization which implements lean six sigma and achieves continuous and breakthrough improvement is characteristic of Ackoff's (1995) 'ideal seeking system' which will be composed of other purposeful and goal seeking systems. Thus to begin to understand lean six sigma implementation in a social organization one must attempt to understand its sub-systems and any system of which it is itself a sub-system. By definition this requires a system of systems approach.

A system of systems may "be of value in directing theorists towards gaps in existing theoretical models and might even be of value in pointing towards methods of filling them" (Boulding, 1956). For instance, helping to produce a unified model of Lean Six Sigma practice, as presented in this chapter, is a new, useful, instantiation of this system of systems in the field of management - drawing on operations management, quality, organizational behaviour, and change and leadership literature. Therein the system of systems concept has helped to integrate current knowledge from many related disciplines into a unified holistic conceptual model representing a move towards an ideal system of systems for lean six sigma, which in turn should increase impact of lean six sigma practice on organizational performance.

Some will state that the field of systems modelling originated in the hard mathematical based discipline of systems dynamics (Forrester, 1961) where philosophically speaking, hard systems exist objectively and mainly contain tangible things. As such, hard systems can be engineered to achieve an optimal solution through hard systems methodologies (HSMs). Thus knowledge and understanding of the systems contained in the physical world may be achieved through the application of HSMs such as repetitive experimentation and hypothesis testing (Zhang, 2010). While this may be appropriate for technological or natural systems it has limited value for human activity systems. To fill this gap soft systems methodologies (SSMs), which are based on the same GST principles, but have a significantly different methods of enquiry have been developed. The SSM approach maintains there are no objective systems outside our minds rather they are perceived by individuals based on their particular worldview. Consequently human activity systems often have no singular objective due to the differing aims and goals of the participants resulting in pluralism in problem definition, situation improvement and solving. Thus the outcomes of SSM interventions are not optimal; instead they are compromises that can be accommodated by stakeholders (Checkland & Poulter, 2006; Senge, 1990). Further, optimizing individual aspects of a system in isolation can result in the sub-optimization of the system as a whole; this is particularly the case in supply chain improvements (Forrester, 1961; Ackoff, 1995). Thus SSM has two functions one of logical analysis (or 'structurisation') and one of socio-cultural analysis (the 'function') and can be considered as "one resource of philosophy of social science in theory and practice" (Zhang, 2010 *pp.*165). In this context SSM serves the requirements of rigor and relevance advocated by Tushmann & O'Rielly (2007).

The SSM concept is, by its nature pluralistic, based on perception with the specific goal of systemic intervention. This is achieved through a dialectic process relying on the tension between the objectivist modeller or enquirer and subjectivist positions of the systemees; thereby acknowledging that human activity systems contain different perspectives and are therefore implicitly contradictory (Houghton, 2009). Therefore it could be argued that human activity system models are formed from epistemological pluralism; or in other words, SSMs use multiple ways of knowing and "understand phenomena from a meta-theoretical vantage point" (Houghton, 2009). While this argument has some value, it does not alter the fact that pluralism is constructed from existing accepted forms of knowledge creation, each of which has the same requirements for rigor and relevance. In this light, systems research could be considered as conducting simultaneous enquiries on the same phenomenon from different theoretical perspectives. Such an approach is desirable for researching lean thinking and six sigma practice because (i) the topic is multi-dimensional and interventions should be acknowledged (ii) interventions will consist of a number of stages each of which may be better served by different methodologies (iii) utilizing several methods will have the potential to both increase the "richness and variety" of ideas and outcomes and improve the reliability of outcomes through the application of theoretical triangulation (Mingers 2003). While this may result in better understanding of particular situations it poses a problem for the modeller-researcher when trying to produce a systems model, particularly one that engulfs all the system of systems properties. Mingers (2003) builds on the work of Checkland and suggests that the vital aspect of the pluralist approach is the effective management of the balance between the problem content system (in this case LSS practice), intellectual resources system (in this case the GST and system of systems literature) and the intervention technique (in this case PrOH modelling and potentially systems dynamics). Consequently the combination of methods may vary during the intervention, as a pluralist perspective would suggest, and the appropriateness of the methodologies being combined must be considered from an ontological and epistemological perspective. Thus, if HSMs are misapplied to human activity systems a researcher-modeller may experience difficulty in comparing the model with reality as the model outcomes often contradict the worldview in which it was conceived; which can even occur with poor SSM applications (Ledington & Ledington, 1999). Empirical studies into the use of pluralistic approaches include Mingers & Taylor, 1992; Munro & Mingers, 2002 and Mingers & Rosenhead, 2004).

In order to mitigate the difficulties of methodological misapplication 'system of systems methodologies' have been developed (Jackson, 1990). However this approach can create difficulties, as with SSMs above, if assumptions (worldview) used when 'reading' the problematic situation turn out to be inappropriate. A similar approach, Integrative Systems Methodology (ISM), uses a framework of opposing perspectives, (e.g. objective and subjective) in order to develop a tension between them allowing effective management of complexity (Schwaninger, 1997). This is also similar to the concept of creative tension promoted by Senge (1990).

3. Contrast of reductionistic and holistic systems thinking

Agricola (1556) developed a systematic analysis approach to operations management by documenting his scientific and empirical evidence and used it to challenge contemporary theory and practice at the time; this was also adopted by the likes of Charles Babbage (1835) to develop "industrially relevant but conceptually robust" advances from the combination of theory and practice. Subsequently F.W.Taylor (1911) developed the 'Law of Heavy Labouring' and the theory of scientific management which, through the identification of key components of performance, standardized and reduced processes to fundamental levels. Both Taylor and Henry Ford (in 1926, reported in Ford, 2003) separated the planning of work from its execution utilizing experts to develop processes which were then implemented by workers. Subsequently, statistical approaches were developed by W. Shewart and W. Gomberg which formed the basis of mass production. In 1971 Mintzberg (1971) challenged Management Science to expand the reductionist approach beyond processes to develop the understanding of management practices to describe them precisely and understand management as a 'programed system'. These attempts to reduce operations management to fundamental components where improvements can be made through data collection and analysis or experimentation proved successful in the early 20th century but have not continued to provide the same level of insight (Sprague, 2007). This is particularly the case when considering the superior performance of Japanese motor manufacturers, who advocated a 'holistic' systemic approach of lean management, compared with their American counterparts, who advocated reductionist approaches (Liker, 2004; Womack *et al*, 1990).

Interest in 'holistic' systems approaches developed in the 1950/60s as a challenge to the one-way causal paradigm of reductionist approaches (von Bertalanffy, 1968). Proponents argue that the World cannot be understood through the decomposition of systems into their component parts. Such systems consist of 2 or more inter-related elements each of which affects the whole; thus the properties and behaviour of each element and its resulting effect on the whole depends on at least one other element. In this context the whole cannot be understood through the aggregation of reductionist parts because the characteristics of the whole are a result of their interactions (Ackoff, 1974). Additionally the reductionist approach was challenged by Forrester (1961) stating that mathematical optima had little applicability to 'real world' problems due to oversimplification becoming devoid of practical interest and therefore utility. Further still, management as an art was more complex, difficult and challenging than mathematics, physics or engineering because of the greater scope of systems and the numerous non-linear relationships that control the course of events. By 1969 Wickham Skinner (Skinner, 2007) began to question how the application of accepted managerial principles in businesses could results in failure; concluding that the optimization of individual aspects, such as production and marketing, could pull in different directions because of their differing goals. Consequently, it is necessary to fit the components together as a strategy, in order that the system functions as a whole to achieve a specific aim.

There are a wide range of methodologies that could be applied in the field of operations management, but for the purpose of this chapter the focus will be on the systems approach and the dominant quantitative and qualitative methodologies therein. In particular, soft systems approaches which aim to produce models of a 'problem situation' to facilitate better understanding, enabling conclusions to be drawn about appropriate corrective action.

3.1 Systems Dynamics (SD)

Systems Dynamics (SD) was developed by Forrester (1961) at MIT as a methodology designed to produce representative models of the complex patterns of dynamic relationships between the 'stocks and flows' of physical or social processes. Using the concepts of ratios, levels, feedback loops and control, the dynamics are assigned causal and mathematical relations, which can then be used to predict the effect of different types and levels of intervention. Philosophically, "problems can be separated from context, and treated in a purely theoretical way, to pursue objective information to find and display a scientifically demonstrable solution" (adapted from Lane & Oliva, 1998 *pp.* 225). Thus by definition, the models are an ontological description of the problem, they are an objective representation of the pre-existing real world independent of context which can be fully observed by a detached researcher. As such they represent a realist and reductionist perspective. Epistemologically knowledge is created through representation by modelling, which can be used to form dynamic hypotheses of how the 'reference mode' (situation under investigation) causes the observed behaviour. SD is a quantitative methodology using observation and measurement combined with judgement and opinion by an analyst to optimize the system under investigation (Mingers, 2003) using a realist, functionalistic, determinist and 'hard' systems methodology fitting into the area of functionalist sociology (Lane, 1999).

In order to model systems using SD and other hard approaches human activities are simplified in order to allow mathematical description of processes. To do this various assumptions are often made (Boudreau *et al.*, 2003):

- people are not a major factor (OM models focus on machinery, frequently omitting human effects)
- people are deterministic and predictable (people have perfect availability, are identical and uniform, task times are deterministic and mistakes are random or do not occur
- workers are independent, individuals unaffected by others
- workers are stationary, workers do not learn, problem solve or exhibit any patterns of behaviour such as fatigue or motivation
- workers support the production or delivery of the service but as not part of it, the impact of system structure on the interaction of customer and worker is ignored
- workers are emotionless
- work is perfectly observable; measurement error and the Hawthorn effect are ignored.

While this moves beyond the simple cause and effect of the natural sciences criticized by Forrester (*ibid)* the effect is to assume that human behaviour is of little consequence. Reacting to this, the field of behavioral operations has emerged, challenging the simplification of human behavior in operations management modeling and questioning a number of assumptions which form the paradigm of operational research. Therefore, hard systems approaches such as SD are subject to many criticisms:

- there is no method for assessing the appropriateness of the chosen worldview or means by which other worldviews can be articulated (Lane & Oliva, 1998)
- they do not consider power and social interactions therefore human actions are rational and neutral
- does not distinguish the problem solving system from the real world problem (Checkland & Poulter, 2006)
- as they do not give refutable hypotheses (Peery, 1972), nor a method for translating models into real world action. As such, SD provides representation of the situation but no ideal vision (Rodrigues & Bowers, 1996).

3.2 Soft Systems Methodology (SSM)

In contrast to SD, SSM is an interpretive approach; as such the real world is not detached from the model, but constructed by those who experience it; hence a real world system is by definition subjective and context specific to the person experiencing it. SSMs are designed to create models of 'real world problem situations' in the 'systems world', so that the participants can better understand the problem and reach an 'accommodation' - a solution acceptable to stakeholders - on action (Checkland & Poulter, 2006; Checkland and Scholes, 1990). Consequently, SSM does not aim to optimize or solve a problem in the way that SD does, but instead sees problems as 'messy' human processes requiring constant negotiation (White, 2009). In SSM, model building is considered to be a social process, a personal experience that can only be understood as a whole, which produces useful devices that can be utilized to "help human agents to create their social worlds via debate and the construction of shared meaning" (Lane, 1999). As such, the different worldviews of the participants regarding the 'real world problem situation' can be considered (Mingers 2003). Ontologically, SSM identifies a real world problem but treats this in an interpretive fashion, thus the world exists in the context of human activity systems (sometimes known as 'holons') which are perceived according to the worldviews of those involved (Mingers, 2003). As such, stakeholders have their own motivations and goals, and real world problems can only be solved as acceptable compromises (Checkland & Poulter, 2006). Knowledge of the problem situation is created (epistemology) through the use of systems concepts, rich pictures and logical relations. Thus hard and soft information about the problem can be assembled in the context of the worldviews of those concerned; as such the information assembled is predominantly qualitative. The models produced can then be used by analysts, researchers, facilitators and the participants to learn about and improve a real world problem situation by achieving consensus on feasible and desirable changes (Mingers, 2003; 2011).

The main criticisms of SSM is that it is difficult to implement, as it is not a problem solving method but rather a method to enable better consideration of the problem at hand. As such, it is difficult to assess the outcome of the SSM which, as a pure qualitative method, cannot produce a measurable outcome. Criticisms of SSM include:

- modelling on the basis of different worldviews makes problem definition difficult, and the selection of a worldview means the real world problem is not modelled instead producing 'ideals' from a particular worldview (Lane & Oliva, 1998)
- no mechanism by which the conclusions can be implemented as it assumes implementation will happen automatically because it is the logical accommodation of stakeholders. Because the output is not a system, the proposed changes are not necessarily systemic and therefore infeasible (Lane & Oliva, 1998) and may lack cybernetic alignment (Flood & Jackson, 1991).

3.2.1 Process Oriented Holonic (PrOH) Modelling

Process Oriented Holonic (PrOH) Modelling is one of the more recent versions of SSM with philosophical bases in GST and system of systems. The purpose of PrOH modelling is to produce a systemic set of models without using a reductionist or mechanistic approach to modelling. This is necessary because human activity systems have high levels of stochastic, non-determinist and sometimes irrational and illogical behaviour (Balogun & Johnson, 2005; Rice, 2008). To approach this from a reductionist perspective would lose information necessary to see ‘hidden’ and ‘emergent’ properties at different organizational levels. As such, PrOH modelling is a methodology effective for linking strategic vision to operational processes. It is best applied to environments of high complexity, low volume and high variety where opportunities for repeated learning are limited; as is typical in LSS implementations in organisations.

PrOH utilizes pictorial models using ‘bubbles’ and linkages to describe processes. Uniquely PrOH defines the ‘scope’ (or area of interest) using three dimensions; pitch, width and length. This allows modellers to properly define their models and allow easier validation. The ‘pitch’ of the model is the organizational level being modelled; it is usually only necessary to use three levels strategic, tactical and operational. The ‘width’ of the model relates to how much detail of the supporting activities of the core process is included and the ‘length’ defines the ‘pick-up’ and ‘drop-off’ points of the model, in other words, its beginning and end.

Each PrOH model is built around a core process, making validation and the level of granularity easy to define, using bubbles to represent ‘nouns’ such as people or things which are linked together using arrows, utilizing verbs to describe the connection or linking arrows. The major advantage of this approach is the promotion of natural language, limiting codification, making the models more accessible to users at all levels. Natural language instead of jargon will make systems thinking more accessible and increase practice (Ackoff, 2006).

In summary, PrOH modelling produce ‘holarchies’ based on abstraction and enrichment suited to complex problems such as implementations of new systems, organisational changes or large high volume and low variety projects. In contrast, hard systems methodologies, such as SD, produce hierarchical models based on aggregation and reduction that are best suited to low variety, high volume relatively short lead time processes such as seen in white goods or automotive manufacturing, where learning opportunities and data collection opportunities are repeatedly available.

While lean thinking and six sigma can utilize specific reductionist tools for their implementation, when considered overall, as a holistic approach, LSS is better suited to GST and system of systems, particularly SSM approaches, which represent the complexities of the processes and organizational change. Therefore the authors recommend that a combined hard-soft approach should be used for modelling LSS projects and programmes.

4. Systems thinking for Lean Six Sigma

Lean thinking and Six Sigma are used to improve unstructured systemic problems, and can help transform organizations when properly deployed; for example, Toyota (Lean thinking), General Electric and AlliedSignal (Six Sigma) are often quoted. Typically organizations have adopted one of these lean or six sigma techniques but, more recently, the combined approach of LSS has emerged as an attempt to fuse the two approaches together in a way that combines their strengths and mitigates their weaknesses. However there is currently no definitive, highly impactful way of achieving this despite high profile successes (Pande, 2000; Kwak, & Anbari, 2006) with tools being widely utilized and accepted by academics and practitioners alike. Therefore, the question must be asked - why do some organizations fail to achieve the results they expect?

Benefits of lean six sigma were initially promoted in management guides by industry gurus (Pande, 2000; George, 2002; Martin, 2006) and subsequently in trade press articles describing successful projects (Anon, 2010; Burgess, 2010). However they are prescribed solutions, a one size fits all solution, which cannot account for observed failures. Thus reasons for differences in deployment success are unclear, stimulating academic research into LSS programmes and their successful implementation. Research approaches utilized fall broadly into five groups (Brady & Allen, 2006):

- case study - often of specific situations with little wider applicability
- comparative - describing relative merits of different techniques
- theoretical with application - modifications to methodology applied to specific situations
- surveys - of application and desirable traits of implementation and sustainability
- literature review - describing gaps in literature, issues and future research.

While the literature provides valuable insight, they are limited in scope and focus on the desirable traits of successes, rather than how the current pool of knowledge might be integrated. Currently there is little rigorous academic examination of the effective implementation of key factors governing the initial and ongoing success of the LSS strategy, and as yet there is no definitive model for its deployment or unified theory with general applicability (Furterer & Elshennawy, 2005; McAdam, & Hallet, 2010; Thomas *et al*, 2009; Tjahjono 2010; Naslund, 2008; Nonthaleerak and Hendry, 2008; Pepper and Spedding, 2010; Proudlove *et al*, 2008). Given that many desirable traits and methodological insights have been identified, there is a need to identify how they can be more effectively integrated and deployed.

Lean thinking and six sigma utilize reductionist tools and statistical analysis applied to processes to improve them, but their success is reliant on the contribution of employees. Consequently, people and teamwork are major factors; therefore it is not logical to assume behaviour is predictable or emotionless (Robbins, 2001). Each technique utilizes workers to problem solve, learn from mistakes and improve processes to deliver what the customer desires. Organizations utilizing these techniques are driven by a focus on quality, efficiency and effectiveness, as defined by their customers and the workforce, as an intrinsic part of this process (Shah & Ward, 2007; Pande, 2000; Womack *et al.* 1990; Clegg *et al.* 2010). Additionally, lean thinking is designed to eliminate the 'hidden factory'; which is present but not often observed by traditional operations management. Thus one could consider lean thinking and six sigma to be modern incarnations of the principles of scientific management in terms of process management, tools and statistics (Chakrabarty and Tan, 2009), but with a significant focus on the human aspects of operations management (Zu *et al*, 2010).

Therefore success of lean thinking and six sigma in practice is not only a result of its scientific origins, but the way in which the workforce is utilized. Therefore approaching issues of implementation and management of lean and six sigma programmes from a purely scientific and reductionist viewpoint cannot address important issues such as the systemic functioning of implementations (Naslund, 2008; Conti, 2010; Kuei & Madu, 2003; Baines *et al*, 2006). For example Clegg *et al.* (2010) conclude the effectiveness of any aspect of lean and six sigma implementations is the product of technical quality and cultural acceptance, not just the summation of reductionist parts. Similarly the emerging field of behavioural operations attempts to merge the perspectives of HRM and OM in order to understand the people aspects of operations management (Boudreau, 2003; Linderman *et al.*, 2006; Bendoly & Hur, 2007).

4.1 Criticisms of LSS

While there is a significant quantity of rigorous empirical evidence to guide the use of LSS, the current methodology does not account for the human side of implementations (Chakravorty, 2009). Indeed widening the concept and application of LSS, to include people and organizational criteria will aid embedding (McAdam & Lafferty, 2004). Additionally organizations must balance flexibility and people-oriented cultural values with the need to maintain control systems (Zu *et al*, 2010) as often deemed critical, even in innovative processes (McComb *et al.*, 2007; Naveh, 2007; Jayawana & Holt, 2009); to achieve this, the organization must continuously adapt (Kwak & Anbari, 2006).

It has been argued that lean thinking, six sigma and LSS are just repackaged versions of earlier techniques, and are all essentially fads (Naslund, 2008). A primary criticism is the isolated nature of lean and six sigma leading to problems of compartmentalization, sub-optimization and fragmentation causing the organization to suffer as a whole (Naslund, 2008). This isolation can result in the benefits of training not being realised (Lu & Betts, 2011). Similarly, Conti (2010) states that strategic fragmentation results from a lack of systemic perspective and there is a joint role for quality and systems thinking in value generation. Thus "quality is not a result of one factor or issue but is rather systemic" (Kuei & Madu, 2003); as current management foci, social and technical system components must be understood and managed through systemic implementation. Further, Naslund suggests "the theories behind systems thinking applied via process management can provide the framework needed to facilitate and maintain successful organizational developments". Thus "a truly successful application of lean requires organization-wide changes in systems practices and behaviour (Baines *et al*, 2006). Other researchers identified a need for a systemic approach to achieve the best results in LSS (Proudlove *et al*, 2008) and appropriate selection of the most rewarding projects (Su & Chou, 2008; Yang & Hsieh, 2009). Additionally, the application of a systemic view has been shown to increase deployment success through organizational learning (Wiklund & Wiklund, 2002). Such learning is vital for an organization to adapt to the needs of the system in which it operates; in this respect prescribed solutions are too simplistic and often fail to account for hidden dynamic systemic issues, which can help to understand potential, distant, time delayed side effects of improvement actions (Senge, 1990). This has led to calls for future research into systems, to combine current knowledge and allow the dynamics of implementation to be monitored, understood and optimized (Brady & Allen, 2006, *pp*.348).

4.2 Towards a solution

Given that the adoption of LSS is an organizational change, it is logical to use tools that are flexible enough to accommodate the dynamics of the process, whilst also providing a way of visualizing the desirable traits and making them accessible to everyone. The systems discipline argues that there is no such thing as an isolated process, that all processes are linked through dynamic interactions that must be considered as such when approaching organizational problems. Systems thinking is a methodological body for studying and managing complex feedback systems such as one finds in business and other social systems. It is an approach in which the model resembles reality structurally so it can be reviewed for usefulness and consistency. Advocates of the method state “until one understands the dynamic cause of present undesirable conditions one is not prepared to explore moving from present conditions to more desirable conditions” (Forrester, 1994). This can be achieved by either of two approaches. Firstly, mapping the dynamic relationships then using a variety of methods to understand the possible consequences of those relationships or develop theory. Secondly, creating a model of the dynamic relationships in a given problem or situation in order to explore the consequence of different amounts of intervention, timing delay and feedback. It is important however to realise that it is not designed to give the right answer but to help consider the problem more effectively (Forrester, 1961; Checkland & Poulter, 2006).

Although the importance of a systemic view is highlighted by authors there is no unified systemic and systematic approach, which is of vital importance for both the successful implementation and maintenance of LSS initiatives. Such an approach could crystallize the knowledge of previous researchers and help to mitigate or eliminate the problems and issues they have identified. Such work could allow the development of a LSS organization rather than an organization carrying out LSS projects.

Unified systemic models may provide a new perspective to the combination of lean and six sigma in the context of systems thinking. In the academic arena this will bring together the previous knowledge and provide an integrated LSS methodology and theoretical model for the deployment of LSS called for in contemporary literature. Additionally applying systems thinking to the LSS field will enhance the ability of practitioners to understand the processes they are trying to change or improve. Superior results will be derived from systemic insight, going beyond quantitative measures inherent to LSS to examine the soft aspects of organizational culture. The ultimate goal of a systemic LSS model would be to produce an organizational structure that is optimized within the LSS framework.

5. A proposed system of systems model for Lean Six Sigma

The overall aim of both Lean Thinking and Six Sigma is to bring about improvements to processes that will benefit the organization as a whole. In order to realize this aim the organization must first assess the needs of the current business environment and translate them into a clearly defined strategy, objectives and goals to form the basis of organizational activities. A LSS Champion should be responsible for promoting the LSS programme and acts as a link between the Executive and the wider organization. As such a LSS Champion considers strategic objectives and goals and develops LSS Projects appropriate to their achievement. These projects are then assigned to and managed by LSS Black Belts; subsequent process improvements are maintained by Process Owners improving the organizations position in a Future Business Environment. These roles and entities (shown as proper nouns in this paragraph) are defined in Figure 1 as the core process for LSS involves development of LSS projects based on the strategic requirements of the business.

The nature and language of PrOH models utilizes the use of natural language to make the models easier to follow reducing the need for the reader to need specialist training and ensuring accessibility for any user. Thus the core process for the strategic level of LSS deployment is shown in the first PrOH model given in Figure 1 which reads as '*The Current Business Environment may require the Executive Board to develop a Strategic Action Plan to inform the Lean Six Sigma Champion who develops Strategic Lean Six Sigma projects which are managed by the Lean Six Sigma Black Belt to improve the Future Business Environment*.' Also, the Executive Board consists of the CEO and representatives from Operations and Finance, similarly the Lean Six Sigma Black Belt is responsible for the management of projects, but they are supported by the Process Owner for the process under consideration in the project. The Strategic Action Plan is shown to focus on growth, acquisition and cost. Through further enrichment at the lower levels, tactical and operational, the nature of these aspects of strategy could be further refined, providing an enriched set of models in a holarchy describing LSS deployment, which have produced using a soft systems approach.

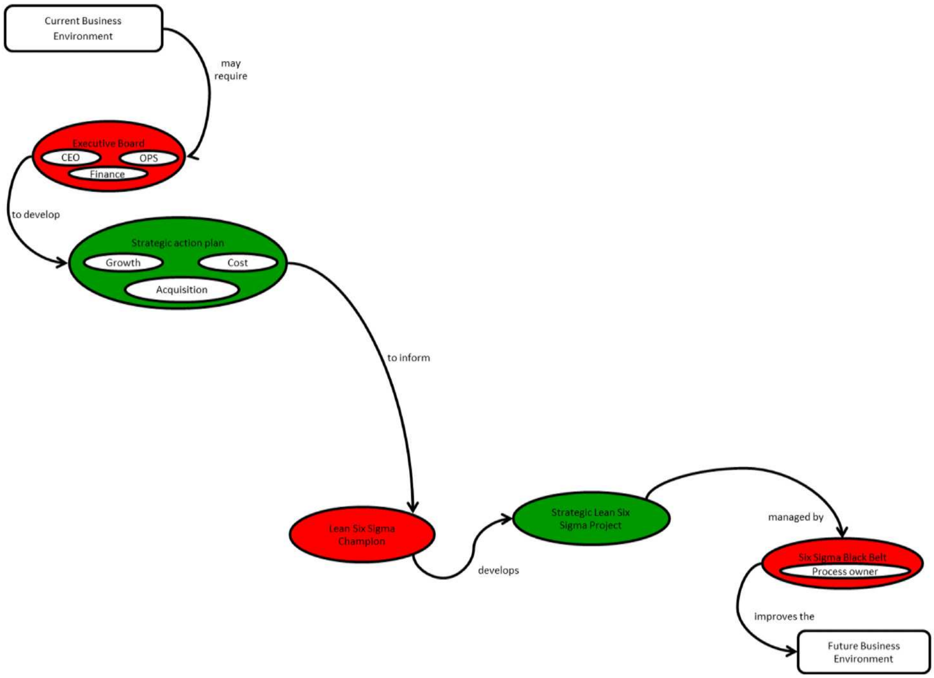

Fig. 1. PrOH Model - Core Process

In order for the core process to be executed effectively it is necessary to have supporting activities to facilitate it, these can be added to the model as in Figure 2. So the development of the '*Strategic Action Plan directs the Departmental Managers to produce Goods and Services which are monitored by Performance Managers who produce Reports to inform the Lean Six Sigma Champion*' who utilize it to develop Strategic LSS Projects. Additionally the reports on the current performance of departments will be used by the LSS Black Belt as part of management of the project. These supporting processes could also be enriched in the same way as the core process. An additional set of supporting processes would cover external aspects such as market data. Thus '*the Strategic Action Plan informs the Customer Relations Manager who collects Customer and Market Data to inform the LSS Champion.*

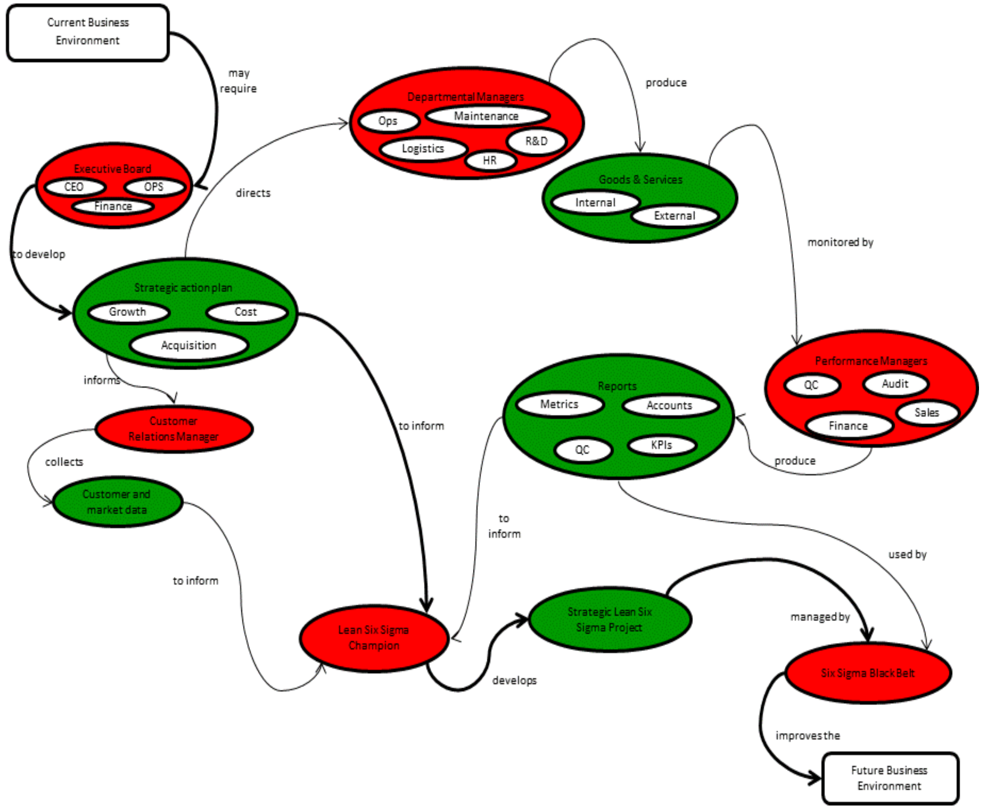

Fig. 2. PrOH Model Showing Supporting Processes for the Core Process

In addition to the strategic initiative to conduct projects; problems may arise in the day-to-day business operations that need to be addressed by LSS projects. One possibility is a change in market conditions such as the emergence of new competitors, market opportunities or changes in customer requirements which require an urgent organizational response. Another possibility is the emergence of problems in the day-to-day operations. Each various department manager will have been assigned objectives and goals through the strategic action plan which have directed them to produce goods and services for their respective internal and external customers. The performance of these departments is then measured and reported against targets by various performance managers/departments, such as quality control and finance. Should these reports identify failures in the organizational performance it may be necessary to conduct LSS projects to rectify them. Additionally this information is vital to the LSS Champion when deciding which potential projects should be given priority and the LSS Black Belt when executing LSS projects.

The 'holistic' lean thinking approach utilizes the 'Deming cycle' of plan-do-check-act (PDCA) to drive continual improvement. The cycle iterates between *planning* and *deploying* long and short term organizational objectives and goals. *Doing* is completing operational activities to achieve those objectives and goals. '*Checking' is* the performance of those activities and *Acting* to improve the *Doing* of those activities leading to a further cycle of plan-do-check-act. *Acting* may be specific projects designed to achieve long and short term goals or ad-hoc improvement actions to address local problems that emerge in day-to-day operations. However lean thinking does not have an explicit mechanism by which projects should be executed with improvement actions being carried out 'as required' and not necessarily benefiting the organization as a whole which is overcome by the incorporation of six sigma into the Act part of the cycle, giving a structured approach to the execution of continuous and breakthrough improvement. Conversely, the addition of the Plan-Do-Check to the formal project approach of six sigma will provide links to organizational strategy and the performance of operational processes necessary to select impactful projects, which is currently missing in traditional six sigma implementations.

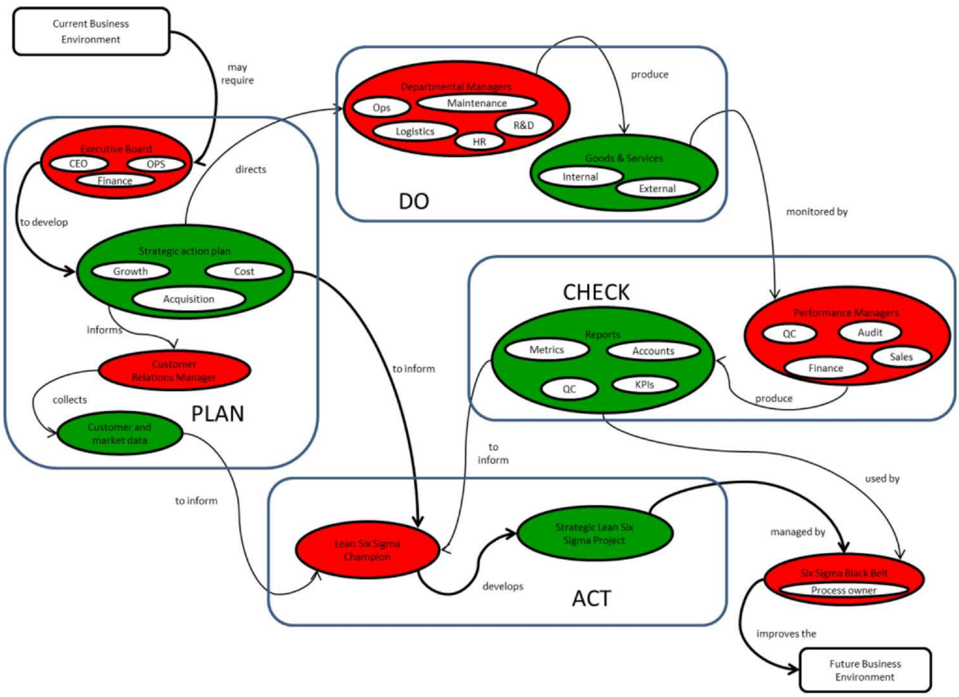

Fig. 3. The Deming Cycle Applied to the Lean Six Sigma PrOH Model

Thus it is beneficial to perceive lean six sigma as described in this chapter - because defining project improvement structures in six sigma decides the method by which the Act part of the lean thinking cycle is achieved and the remaining iterative part of the Plan-Do-Check cycle provides necessary structure for the selection and development of appropriate LSS projects that lead to the achievement of tactical and strategic objectives. Figure 3 shows Deming's Plan-Do-Check-Act cycle imposed upon the Lean Six Sigma PrOH model. The reason for doing this is to show that a SSM such as PrOH can be used to describe the LSS paradigm, whilst a more quantitative meta-system (such as the Deming cycle) can be super-imposed on it (shown by large blue boxes), in which systems dynamic performance measures can be applied. Such metrics should be based on the costs of quality - failure, prevention and appraisal (Kiani, *et al.*, 2009, Pavlov and Bourne, 2011). The implications for managers is that they need to ensure that the activities of an organisation, which can be shown in enriched PrOH models at strategic, tactical and operational levels need to be aligned with metrics in the meta (PDCA) measurement system.

6. Conclusion

Systems approaches can provide representative models of the real world and move beyond the general simplistic linear cause-and-effect relationships which are appropriate to physical systems. Indeed such an approach is necessary if human understanding of the world is to move beyond the superficial, simplistic mechanistic models (Boulding, 1956). By utilizing systems thinking and drawing on a range of literature, the possibility of creating holistic understanding, unconstrained by ontological or epistemological tradition, whilst maintaining academic rigor, may be achieved. Additionally, correctly applied, systems approaches can produce models that are more relevant to praxis; resulting in methods and approaches that can facilitate desirable changes in organizational policy deployment (Akao, 1991) rather than abstract, theoretical, 'academic' solutions.

While PrOH modelling provides a valuable tool for the modelling and discussion of the structure of LSS processes as applied in this chapter, it is limited to qualitative assessment of human activity systems. PrOH is of value in the development and understanding of the unification of lean and six sigma as it can provide an ideal view of LSS. However, it does not provide a method by which the appropriateness of the conclusion can be quantitatively assessed. Thus the model as in Figure 3 may be defensible but it does not provide a method to assess its quantitative ability to produce the desired outcome. By combining PrOH modelling with a meta-measuring system based on Deming's Plan-Do-Check-Act cycle using cost of quality metrics in an SD model it should be possible to produce models that clearly articulate LSS processes (PrOH) and a method that can quantitatively assess the feasibility and behaviour of the proposed models (SD) together, which should facilitate the increased impact of LSS deployments; this is the subject of on-going work by authors and sponsors.

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8. References

Ackoff, R.L. (2006) "Why Few Organizations Adopt Systems Thinking", *Systems Research and Behavioral Science Vol.* 23 *pp.* 705-708, ISSN 10927026.

Ackoff, R.L. (1995), "'Whole-ing' the Parts and Righting the Wrongs", *Systems Research. Vol.* 12 (1) *pp.* 43-46, ISSN 07317239

Ackoff, R.L. (1971), "Towards a System of Systems Concepts", *Management Science. Vol.*17 (11) *pp.* 661-671, ISSN 00251909

Agricola, G., "*De Re Metallica*". Froben, Basel. 1556. ISBN 1154680657

Akao, Y. Ed. "*Hoshin Kanri: Policy Deployment for Successful TQM*" Productivity Press, NY, 1991. ISBN 9781563273117

Anon, *Quality Magazine*., BNP Media, 2010, *pp*.48-51

Balogun, J. & Johnson, G. (2005), "Intended Strategies to Unintended Outcomes", *Organization Studies. Vol*. 26 (11) *pp*.1573-1601, ISSN 01708406

Babbage, C. "*On the Economy of Machinery and Manufactures*", Charles Knight, Pall Mall, London 1832. ISBN 0678000018

Baines, T. Lightfoot, H. Williams, G. M. & Greenough, R. (2006),"State-of-the-art in lean design engineering: a literature review on white collar lean", *Journal of Engineering Manufacture. Vol*. 220 (9) *pp*. 1539-1547, ISSN 09544054.

Battista, J.R., 'The Holistic Paradigm and General Systems Theory', *General Systems*, XXII, 1977.

Bertalanffy, L. von, *General Systems Theory*. Brazillier, New York. 1968, ISBN 0807604534

Beer, S. *Diagnosing the Systems for Organisations*. Wiley, Chichester. 1985.

Bendoly, E. & Hur, D. (2007), "Bipolarity in reactions to operational 'constraints': OM bugs under an OB lens.", *Journal of Operations Management. Vol*. 25 *pp*.1-13, ISSN 02726963

Boudreau, J. Hopp, W. McClain, J.O. & Thomas, L.J. (2003) "On the interface between operations and human resources management", *Manufacturing and Service Operations Management. Vol*. 5 (3) *pp*.179-202, ISSN 15234614

Boulding, K., (1956) 'General Systems Theory - the Skeleton of Science'. *Management Science*. Vol. 2. pp 197-208, ISSN 00251909

Brady. J. E. & Allen T.T. (2006), "Six Sigma Literature: A Review and Agenda for Future Research", *Quality and Reliability Engineering International*. *Vol*. 22 (3) *pp*.335-367, ISSN 07488017

Burgess, D., *Quality Magazine*. BNP Media, 2010, *pp*. 42-45

Chakravorty, S.S. (2009), "Six Sigma programs: An implementation model." *International Journal of Production Economics. Vol*. 119 (1) *pp*.1-16, ISSN 09255273.

Checkland, P.B., (1988) 'Soft Systems Methodology: An Overview'. *J. of Applied Systems Analysis*. Vol. 15. pp27-30, ISSN 03089541

Checkland, P. & Poulter, J. *Learning for action: a short definitive account of soft systems methodology and its use for practitioners, teachers and students*. Wiley. 2006, ISBN 0470025549

Checkland, P. & Scholes, J. "Soft Systems Methodology in Action", Wiley, 1990, ISBN 0471986054

Churchman, C.W., '*The Systems Approach*'. Dell Publishing. NY. pp11. 1968, ISBN 0440384079

Clegg BT, (2007) '*Building a Holarchy using Business Process Orientated Holonic (PrOH) Modeling'*. IEEE Systems, Man and Cybernetics: Part A. Vol.37, No.1. pp.23-40, ISSN 10834427

Clegg, B. Rees, C. & Titchen, M. (2010), "A study into the effectiveness of quality management training: A focus on tools and critical success factors", *The TQM Journal. Vol*. 22 (2) *pp*. 188-208, ISSN 17542731

Conti, T. (2010), "Systems thinking in quality management", *The TQM Journal. Vol*. 22 (4) *pp*. 352-368, ISSN 17542731

Forrester, J.W., *Industrial Dynamics*. Waltham: Pegasus Communication, 1961, ISBN 1883823366

Forrester, J.W. (1994), "System dynamics, system thinking and soft OR", *System Dynamics Review. Vol.* 10 (2-3) *pp.* 245-256, ISSN 08837066.

Flood, R.L. & Jackson, M.C. *Creative Problem Solving: Total Systems Intervention.* Wiley, Chichester, 1991, ISBN 0471930520

Ford, H., "*Today and Tomorrow*". Productivity Press, Portland Oregon, 2003

Furterer, S. & Elshennawy, A.K. (2005), "Implementation of TQM and Lean Six Sigma tools in local government: A framework and a case study", *Total Quality Management and Business Excellence. Vol.* 16 (10) *pp.*1179-1191.

George, M. L. "*Lean Six Sigma: Combining Six Sigma Quality with Lean Production Speed*", Blacklick, OH, USA: McGraw-Hill Professional Publishing, 2002

Houghton, L. (2009). "Generalization and Systemic Epistemology: Why should it Make Sense?", *Systems Research and Behavioral Science. Vol.* 26 *pp.* 99-108, ISSN 10927026.

Jackson, M.C. (1990). 'Beyond a System of Systems Methodologies'. *The Journal of the Operational Research Society. Vol.* 41 (8) *pp.* 657-668, ISSN 01605682

Jackson, M.C., (1995). 'Beyond the Fads; Systems Thinking for Managers'. *Systems Research.* Vol. 12. No. 1, pp25-42, ISSN 10991735.

Jayawarna, D. & Holt, R. (2009), "Knowledge and quality management: An R&D perspective", *Technovation. Vol.* 29 (11) *pp.* 775-785, ISSN 01664972

Kuei, C-H. & Madu, C.N. (2003), "Customer-centric six sigma quality and reliability management", *International Journal of Quality and Reliability Management. Vol.* 20 (8) *pp.* 954-964, ISSN 0265671X

Kiani, B., Shirouyehzad, H., Bafti, F.K., Fouladgar, H. (2009), "System dynamics approach to analysing the cost factors effects on cost of quality" *International Journal of Quality & Reliability Management*, Vol. 26 (7)

Kwak, Y.H. & Anbari, F.T. (2006), "Benefits, obstacles and future of six sigma approach", *Technovation. Vol.* 26 (5/6) *pp.* 708-715, ISSN 01664972

Lane, D.C. & Oliva, R. (1998), "The greater whole: Towards a synthesis of systems dynamics and soft systems methodology", *European Journal of Operational Research. Vol.* 107 *pp.* 214-235, ISSN 03772217.

Lane, D.C. (1999), "Social theory and systems dynamics practice", *European Journal of Operational Research. Vol.* 113 *pp.* 501-527, ISSN 03772217.

Ledington, P.W.J & Ledington, J. (1999). 'The Problem of Comparison in Soft Systems Methodology'. *Systems Research and Behavioral Science. Vol.* 16 *pp.* 329-339, ISSN 10927026.

Liker, J.K. "*The Toyota way: 14 management principles from the world's greatest manufacturer*" McGraw-Hill. 2004

Linderman, K. Schroeder, R.G. & Choo, A.S. (2006), "Six Sigma: The role of goals in improvement teams", *Journal of Operations Management. Vol.* 24 *pp.* 779-790, ISSN 02726963

Lu, D. & Betts, A. (2011), "Why process improvement training fails.", *Journal of Workplace Learning. Vol.* 23 (2) *pp.* 117-132, ISSN 13665626

Martin, J.W. "*Lean Six Sigma for Supply Chain Management: The 10 Step Solution Process*", McGraw-Hill Professional. 2006, ISBN 0071479422

McAdam. R. & Hallet. S.A. (2010), "An absorptive capacity interpretation of Six Sigma.", *Journal of Manufacturing Technology Management. Vol.* 21 (5) *pp.* 624-645, ISSN 1741038X

McAdam. R. & Lafferty. B. (2004), "A multilevel case study critique of Six Sigma: Statistical control or strategic change.", *International Journal of Operations and Production Management. Vol.* 24 (5/6) *pp.* 530-549, ISSN 01443577

McComb, S.A. Green, S.G. & Compton, W.D. (2007), "Team flexibility's relationship to staffing and performance in complex projects: An empirical analysis", *Journal of Engineering Technology Management. Vol.* 15 (5) *pp.* 293-313, ISSN 09234748

Mingers, J. (2011) "Soft OR comes of age – but not everywhere", *Omega. Vol.* 39 (6) *pp.* 729-741, ISSN 03050483.

Mingers, J. (2003) "A classification of the philosophical assumptions of management science methods", *Journal of the Operational Research Society. Vol.* 54 *pp.* 559-570, ISSN 01605682.

Mingers, J. & Rosenhead, J. (2004), "Problem Structuring Methods in Action", *European Journal of Operational Research. Vol.* 152 (3) *pp.* 530-554, ISSN 03772217.

Mingers, J. & Taylor, S. (1992), "The Use of Soft Systems Methodology in Practice", *Journal of the Operational Research Society. Vol.* 43 (4) *pp.* 321-332, ISSN 01605682.

Mintzberg, H. (1971) "Analysis from observation", *Management Science Vol.* 18 (3), pp. B97–B110 ISSN 00251909

Munro, I. & Mingers, J. (2002), "The use of multi-methodology in practice – results of a survey of practitioners", *Journal of the Operational Research Society. Vol.* 53 *pp.*369-378, ISSN 01605682

Naslund. N. (2008), "Lean, Six Sigma and Lean Sigma: Fads or real process improvement methods?", *Business Process management Journal. Vol.* 14 (3) *pp.* 269-287, ISSN 14637154

Naveh, E. (2007), "Formality and discretion in successful R&D projects", *Journal of Operations Management. Vol.* 25 *pp.* 110-125, ISSN 02726963

Nonthaleerak. P. & Hendry. L. (2008), "Exploring the Six Sigma phenomenon using multiple case study evidence", *International journal of Operations and Production Management. Vol.* 20 (3) *pp.* 279-303, ISSN 01443577

Pande, P.S., "*The Six Sigma Way: how GE, Motorola, and other top companies are honing their performance*", McGraw-Hill. 2000, ISBN 9780071358064

Peery, N.S. (1972) "General Systems Theory: An Enquiry into its Social Philosophy", *The Academy of Management Journal. Vol.* 15 (4) *pp.* 495-510, ISSN 19480989

Pavlov, A. & Bourne, M. (2011), "Explaining the effects of performance measurement on performance and organizational routines perspective", *International Journal of Operations and Production Management. Vol.* 31 (1) *pp.* 101-122, ISSN 01443577

Pepper, M.P.J and Spedding, T.A. (2010) 'The evolution of Lean Six Sigma', *International Journal of Quality & Reliability Management*, Vol. 27 (2), pp.138-155

Proudlove, N. Moxham, C. & Boaden, R. (2008), "Lessons for lean in healthcare from using Six Sigma in the NHS", *Public Money and Management. Vol.* 28 (1) *pp.*27-34 ISSN 09540962

Rice, R.E. (2008), "Unusual Routines: Organizational (Non)Sensemaking", *Journal of Communication. Vol.* 58 *pp.* 1-19. ISSN 00219916

Robbins, S.P. "*Organizational Behavior*", 9th Ed., Prentice-Hall Inc., New Jersey. 2001, ISBN 0130617210

Rodrigues, A. & Bowers, J. (1996) "Systems dynamics in project management: A comparative analysis with traditional methods", *System Dynamics Review. Vol.* 12 (2) *pp.* 121-139, ISSN 08837066

Schwaninger, M. (1997). 'Integrative Systems Methodology: Heuristic for Requisite Variety', *International Transactions in Operational Research. Vol.* 4 (4) *pp.* 109-123, ISSN 09696016.

Senge, P., '*The Fifth Discipline: The art and Practice of the learning Organisation*'. Doubleday/ Currency. NY. 1990, IBSN 0385517254

Shah, R. & Ward, P.T. (2007), "Defining and developing measures of lean production", *Journal of Operations Management. Vol.* 25 *pp.* 758-805, ISSN 02726963

Skinner, W. (2007) Manufacturing strategy: the story of its evolution, *Journal of Operations Management Vol*. 25 (2), pp. 328–335 ISSN 02726963

Sprague, L.G. (2007), "Evolution of the field of operations management", J*ournal of Operations Management. Vol.* 25 (2) *pp.*219-238, ISSN 02726963

Su. C. & Chou. C. (2008), "A systematic methodology for the creation of six sigma projects: a case of a semiconductor foundry", *Expert Systems with Applications. Vol.* 34 (4) *pp.* 2693-2703, ISSN 09574174

Taylor, F.W., "Shop Management", Harper & Brothers Publishers, New York and London 1911, ISBN 1153738376

Thomas, A. Barton, R. & Chuke-Okafor. C. (2009), "Applying Lean Six Sigma in a small engineering company – a model for change", *Journal of Manufacturing Technology Management. Vol.* 20 (1) *pp.*113-129. ISSN 1741038X

Tjahjono. B. Ball. P. Vitanov. V.I. Scorzafave. C. Noguiera. J. Calleja. J. Minguet. M. Narasimha. L. Rivas. A. Srivastava. A. Srivastava. S. & Yadav. A. (2010), "Six Sigma: a literature review", *International Journal of Lean Six Sigma. Vol.*1 (3) *pp.* 216-233, ISSN 20404166

Tushman, M. & O'Rielly, C. (2007). 'Research and Relevance: Implications of Pasteur's Quadrant for Doctorial Programs and Faculty Development', *Academy of Management Review. Vol.* 50 (4) *pp.* 769-774, ISSN 03637425

Waelchli, F. (1992) 'Eleven Theses of General Systems Theory (GST)'. *Systems Research*. Vol. 9, No. 4, pp3-8. ISSN 07317239

Weinburg, G.M., '*An Introduction to General Systems Thinking'*. Wiley, NY. 1975, ISBN 0932633498

Wiklund. H & Wiklund. P.S. (2002), "Widening the Six Sigma concept: An approach to improve organizational learning", *Total Quality Management & Business Excellence. Vol.*13 (2) *pp.* 233-239, ISSN 14783363

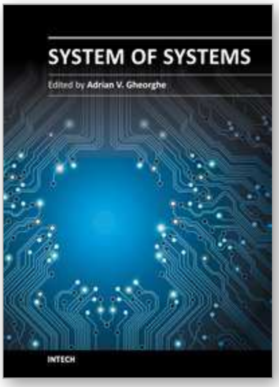
White, L. (2009), "Understanding problem structuring methods interventions", *European Journal of Operational Research." Vol.*199 *pp.* 823-833, ISSN 03772217.

Womack, J.P., Jones, D.T. & Roos, D., "*The Machine That Changed the World.*", 1st ed., 1990, Rawson Associates, Macmillan Publishing Associates, New York, 1990. ISBN 0892563508

Yang. T. & Hsieh. C. (2009), "Six Sigma project selection using national quality award criteria and Delphi fuzzy multiple criteria decision-making method", *Expert Systems with Applications. Vol.* 36 (4) *pp.* 7594-7603, ISSN 09574174

Zhang, H. (2010). 'Soft Systems Methodology and 'Soft' Philosophy of Science', *Systems Research and Behavioral Science Vol.*27 *pp.* 156-170, ISSN 10927026.

Zu, X. Robbins, T.L. & Fredendall, L.D. (2010), "Mapping the Critical Links Between Organizational Culture and TQM / Six Sigma Practices", *International Journal of Production Economics. Vol.* 123 (1) *pp.* 86-106, ISSN 09255273.



System of Systems

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The present book proposes and fosters discussion on the current applications in the field of system of systems, with emphasis on the implications of the fact that new developments and area of technical and non-technical applications are merging. The book aims to establish an effective platform for communication among various types of practitioners and theory developers involved in using the system thinking and systems engineering approaches at the scale of increased complexity and advancing computational solutions to such systems.