International Journal of Logistics Manag

Revisiting the whole systems approach: designing supply chains in a turbulent world

Journal:	*International Journal of Logistics Management*
Manuscript ID	IJLM-02-2021-0121.R3
Manuscript Type:	Original Article
Keywords:	Supply chain innovation, Supply chain strategy, Supply chain competences, Supply chain re-design, Supply chain integration
Research Method:	Conceptual research
Geography:	Europe, North America

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Abstract

Purpose

The systems approach is an exemplar of design science research (DSR), whereby specific designs yield generic knowledge. DSR is increasingly being adopted in logistics and operations management research, but many point to neglect of the human aspects of solutions developed. We argue that it is possible to look back at the history of the systems movement to seek precedent for 'dealing' with the social components, providing a methodologically pluralistic 'research design' framework. Thereby, systems approaches are foundational to providing a design-based 'science' to progressing the logistics and supply chain management field, dealing with contemporary topics such as resilience.

Approach

We undertake a discursive assessment of relevant streams of engineering, social science and systems research, with a conceptual development of how the latter influences supply chain design approaches.

Findings

Building on a phenomenological framework, we create a generic design science research design (DSRD) that enables researchers to choose and integrate the right tools and methods to address simple, complicated and complex problems, dealing with technological, process and social problems.

Originality

We argue that the systems approaches offer methodological pluralism by which a generic DSRD may be applied to enhance supply chain design. We show the relevance of the DSRD to supply chain design problems including in reducing supply chain dynamics and enhance resilience. In doing so, the study points towards an integrated perspective and future research agenda for designing resilient supply chains.

Research limitations/implications

The DSRD provides a framework by which to exploit a range of methodological stances to problem solving, including quantitative modelling perspectives and 'soft' systems social science approaches.

Four substantive gaps are identified for future research – establishing the root cause domain of the problem, how to deal with the hierarchy of systems within systems, establishing appropriate criteria for the solution design and how best to deal with chaotic and disordered systems.

Key words: supply chain innovation, supply chain competences, supply chain strategy, supply chain redesign, supply chain integration

1. Introduction

The intertwining of the physical and the virtual is creating unprecedented challenges. With fast paced technological changes, the amalgamating of the artificial with the human in a new cyber-physical world has been compared to trying to design an aeroplane while flying given that there are no viable pre-existing reference models from the old physical world of how to do it. And even recent cyber-physical examples are soon outdated (Trevino, 2020).

Such technological disturbances are also impacting the logistics sector. It is predicted that by 2040, with greater exploitation of digital technologies, goods consumed and manufactured will be delivered by 'self-thinking' supply chains (Mangan and McKinnon, 2019) that adapt to the demands of increased regulation, price competition and pressures to become more sustainable in the face of Global Warming and lower use of fossil fuels. Coupled with disturbances leading to world-wide impacts, such as financial crises, wars, pandemics and natural disasters, the Council of Supply Chain Management Professional's (CSCMP) 2020 "State of Logistics Report" foretells that supply chains need to be designed to be more resilient, with the ability to adapt and reconfigure. Noting the emergence of digitalisation, the report suggests such technology provides the means for meeting future disruption challenges but that there is also the need for due consideration of the human element to work alongside the new technology rather than be totally replaced.

While Lyall et al. (2018) have questioned the role of humans in managing the digitalised supply chain, Min et al. (2019) suggest that there is still a role for people and there is a need to rethink the way supply chains are designed in order to be resilient to disturbances. A review of supply chain researchers' opinions indicates that the human aspect of supply chain research is much neglected and an avenue for future research is the design of resilient supply chains with due consideration of complexity (Wieland et al., 2016).

The human aspect of operations and supply chain management research is often seen as the domain of the social sciences where the tradition has been description-driven research unlike the physical and life sciences that are prescriptive-driven (Aken, 2004). The latter is a necessary requirement for social scientists to address the challenges of a turbulent world where problems are often 'messy' (Brewer, 2013, Delbridge, 2014) and as articulated in 'soft' systems terms by Ackoff's (1994) concept of 'messes' i.e. the need for managers to address interrelated problems found in social systems. Problem solving approaches allow for the avoidance of formulaic and incremental findings and leads to opportunities for innovative and impactful research (Alvesson and Sandberg, 2013).

Realising the limitations of merely observing and reflecting on the world, design science research (DSR) has recently been (re)discovered in logistics and operations management as a practice-oriented research philosophy whereby specific designs, of business processes or systems, lead to specific interventions (Chandrasekaran et al., 2021) but which yield generic insights and knowledge (Holmstrom and Ketokivi, 2009, Soinio, 2012, Aken et al., 2016). Using this approach, emphasis is placed on understanding the problem, designing a solution and developing it through cycles of testing and redesign (Aken et al. 2016). DSR has its origins in the professional disciplines, such as engineering and medicine, that seek to solve problems with solutions, or designs, that can have generic applicability (Simon, 1988). Aken et al. (2016), calling for more DSR in the operations management domain, conclude that DSR *"in the social domain is a still-developing research strategy, also in OM".* They further note that a *"key OM research issue for DSR is dealing with the social components".*

We agree with the need for a more prescriptive design science approach to research. As the landscape of where we undertake our research is ever changing, analogous to control systems for an aeroplane being designed while we fly it, we contend that it is not necessary to always start with a blank sheet of paper in developing a research design method but that it is possible to look back at the history of systems research to seek precedent for 'dealing' with the social components, as well as their integration with technical and process solution design. By revisiting the systems approach, we observe a wealth of understanding pertaining to the design of socio-technical systems, which can strengthen the DSR calls for more research, but also note that there is a need to develop a guidance on how to combine different disciplinary lenses, with their associated philosophies and methodologies, to allow supply chain designers to better understand the fundamental features of the problem domain to develop appropriate solutions. To explore this argument, there is a need to highlight, discuss and critique links between DSR, systems engineering, design engineering and, logistics and supply chain bodies of knowledge.

It is interesting to note that Simon (1988) highlighted 'systems engineering' as one of the disciplines that promulgates the 'science of design'. In the arguments and examples given, Simon (1988) refers to some "systems" concepts, such as, goal-seeking properties, hierarchy and complexity, although these are merely a few of the many attributes of "a system of system concepts" (Ackoff, 1971).

Despite such systems notions falling within General System Theory (GST) and intended to enable generic 'laws' to be identified to allow analogical learning between disciplines (Bertalanffy, 1950), Simon (1988), among others (e.g. Jenkins, 1969), articulated a positivistic approach to design, building on quantitative operational research and engineering techniques (Cross, 2001). Hence, there is an emphasis on achieving 'optimum' designs, which is prevalent in supply chain research (Gammelgaard, 2004) even to this day, with calls "to capture and analyze [supply chain] data and making <u>optimal</u> decisions" (our underlining – Min et al., 2019). Perhaps this is not surprising given that GST may be defined as a "logico-mathematical field" (Bertalanffy, 1950). Even so, part of the systems engineering ethos, as with engineering design (Dixon, 1966), articulates the need for considering the human aspects (e.g. Jenkins 1969, Parnaby, 1979, Simon, 1988, Towill, 1992) to go beyond the positivistic epistemology towards a more constructivist research philosophy (Cross, 2001 citing Schön, 1983). Most notably, Checkland (1999), building on Jenkin's (1969) systems engineering approach, advocating a social science perspective, developed the soft systems methodology (SSM).

While transferring engineering methods into a social science context is still seen as a challenge (Aken et al., 2016), we argue that there are already well-established approaches that take due account of technology (artefacts), processes (organisational structures) and attitudes (human aspects). But much of what has appeared in the past has been forgotten. Given this, and the changing landscape for supply chains as outlined in the aforementioned text, it is timely to re-evaluate the 'design' perspective for supply chains, to see what is still relevant from the past, to develop a new perspective and position, in order to drive a new research agenda to shape the future of resilient supply chain design.

Therefore, the aim of this paper is to revisit systems approaches to logistics and supply chain research to propose how best to align the solution design to the problem domain, taking into account well established research tools and techniques to underpin the outcomes of DSR with due consideration of people, technology and processes.

While it is claimed that the substantive output from DSR is the generic design (Aken et al., 2016), we argue that the design science 'research design' (DSRD), and associated research tools and techniques, require due attention as it underpins the outcomes of DSR. We argue for a generic DSRD scheme, to answer the question;

what systems approaches are available to ensure valid and credible design solutions to logistics and supply chain problems and where are there gaps in their application?

We believe that the generic DSRD scheme can be adapted and refined to suit a particular problem based on the degree of uncertainty faced in the problem i.e. how well is the problem defined? It is the generic DSRD scheme that then needs further testing and validating in further research. Hence, our contribution is in the 'science of design' that supports the deliverables from DSR (Cross, 2001).

Our paper is conceptual, where we exploit a "discursive alignment of interpretation" (Seuring and Gold, 2012), a qualitative approach where we look for themes or topics from the literature (Ma et al., 2010) which we believe are relevant to the paper's aim and research question. Conceptual articles play an important role in the knowledge development process, and as such, in our approach, we focus on 'conceptual development' (Yadav, 2010). Our conceptualization may be seen as a process of envisioning, explicating, relating, and debating (Macinnes, 2011) -

- *envisioning* – through examination of, and reflection on, the literature, we identified current use of DSR in logistics and propose future DSR approaches
- *explicating* – through an analysis and classification of the literature, we delineate different areas of the systems movement and summarising the link with DSR designs.
- *relating* – Based on published systems tools and techniques, we differentiate suitable application domains to give an integrated approach.
- *debating* – We refute the lack of historical precedent for addressing the central role of people in DSR and advocate learning from the history of the systems movement and approaches.

Given our motivation and aim we started with two strands of literature data collection. Firstly, backward snowballing from Aken et al. (2016) by interrogating the reference list. Secondly, refamiliarizing ourselves with texts on engineering design and systems engineering we were already conversant with and then forward snowballing from those text to see where they were cited. For the second strand, we build on several strands of relevant engineering research notably engineering design (Dixon, 1966, 1987) and systems engineering (Jenkins, 1969), the latter having explicitly influenced manufacturing systems (Parnaby, 1979), supply chain management research (Towill, 1991, 1992) and SSM (Checkland, 1999).

To gather feedback, and strengthen validity, findings were subjected to internal peer review (research group presentations, draft of the paper subjected to critique and discussion) and external peer review via presentation of a working version of the paper at an internal logistics conference and several iterations of the journal peer review process leading to the latest version of the paper. While our paper is prone to our own subjectivity, we believe this is appropriate given that the paper is a conceptual piece wherein we ascertain the discourse around the development and application of DSR and the role of the systems approach, as per empirical research e.g. Laine and Vaara (2007). In exploiting discursive analysis, we determine the limitations of the existing methods and propose a DSRD that exploits a phenomenological decision-making framework (Snowden, 2002, Kurtz and Snowden, 2003).

As we will explain, we believe that the framework has resonance with systems approaches and our own methodological pluralism. As two co-authors, one with a systems engineering background and the other a management social scientist, we suggest that systems thinking by its very nature has its own pluralism (e.g. from 'hard' systems engineering, through 'hybrid' system dynamics and 'soft' system methodology e.g. see Mingers, 2017, Naim et al., 2019) embracing multi-, cross- and interdisciplinarity and requires a contingency based approach to research design, as suggest by Norgaard (1989). Such methodological pluralism is also called for by the logistics and supply chain management community generally (Gammelgaard, 2004, Darby et al., 2019) and more specifically within the context of digitalisation (Wang et al., 2019).

The following section establishes a chronological outline of pertinent thinking for understanding the logic of design across a range of research areas of endeavour. Given the prevalence of systems concepts in design science, we then argue, in Section 3, for the need to revisit the systems approach to problem solving within the context of finding the right tools and techniques for the specific problem domain. In Section 4 we then give our synthesised generic DSRD considering both qualitative and quantitative techniques to solve a well-known supply chain dynamics problem (Naim et al., 1994). Before we conclude and give future research directions, in Section 5 we reflect on some of the challenges and considerations for researchers in exploiting a systems approach to DSR.

2. The logic of design in research: systems, engineering, and design science

2.1 The design of production systems

Jenkins (1969) defines systems engineering as "the science of designing complex systems in their totality to ensure that the component sub-systems making up the system are designed, fitted together checked and operated in the most efficient way". At the same time, he highlights that "the first property of a system is that it is a complex grouping of human beings [including management and technical teams] and machines". The system has to be "designed in such a way that each component and human being is ready to play its designed role efficiently in making the [system] achieve its predetermined [multiple] objectives" with the purpose of solving a complex problem.

Parnaby (1979) exploits a similar approach to the design of manufacturing systems noting that "[m]anufacturing systems involve many people and exist to serve people". Manufacturing systems "interact in complex ways… with our social system and physical environment" facing the need to achieve economic performance in "increasingly complex interactions and constraints of a technical and sociological nature" with different manufacturing systems facing "differing interactions with the social and business environment." The main aim of the manufacturing systems design is to attain operational and long-term stability by adapting to changes in the internal structure (e.g. machine breakdowns, absenteeism) and/or the external environment (e.g. market-place, supply-base).

In achieving adaptability, Parnaby (1979) claims that the human element is critical. The physical manufacturing processes can be automated and produce information that needs to be exploited by management in decision making. Such decision making may build on quantitative 'optimised' designs for real-time operations but need to be translated into 'rules-of-thumb' for practical management purposes. This relates to established production control principles in which much of the routine tasks can be controlled through automated systems but exceptions, such as disturbances, need human intervention.

Towill (1991) uses Jenkin's approach to advocate the merits of systems engineering in instigating change in manufacturing systems. Towill (1991) argues that, when it comes to organisational matters, where the human attitudinal aspects of change are considered in parallel with technological and process factors, then much time and effort is necessary due to the inherent complexity of such systems. Towill (1991) suggests that Parnaby's (1979) approach has particular merits in teasing out the so-called 'soft', or human, aspects of manufacturing systems. As the output of one manufacturing system may be the input to another, Towill (1992) recommends that systems engineering change management is extended to the design of supply chains. Towill's (1992) focus is on the design of production planning and control systems of supply chains.

The above suggest that systems theory has taken several forms, where there is a clear notion of 'design' and a requirement to consider the spectrum of 'soft-hard' systems approaches that meet the needs of the situation (Towill, 1991, Naim et al., 2017).

2.2 The design of engineered products and artefacts

Dixon and Duffey (1990) differentiate engineering design from industrial design. The former relates to the development of a product from its technical conception through detail design, and the design of the related manufacturing process and tooling. The latter is concerned with the styling and may be a part of, or runs in parallel with, engineering design. Noting that design has its roots as an artistic endeavour, hence originates from the arts and humanities, Dixon (1966, p.8, 1987) indicates the need for due consideration of the various influences of the fundamental disciplines on engineering designers, including the physical sciences, social sciences and economics. As well as the fundamentals, product designers also must be aware of product manufacturability, so knowledge of manufacturing systems and engineering technology is a necessity. Such a broad knowledge base aligns with the tenets of systems engineering.

The engineering design of a product is intrinsically a complex endeavour involving due consideration of people, organisations, processes and the physical world, such as in-progress design, manufacturing and the external environment (Dixon, 1987). Engineers more generally are dealing with design problems and that "engineering is science-based problem solving with social-human awareness" (Dixon, 1966, p4).

Building on the engineering discipline, Simon (1988) suggested that "[d]esign… is the core of all professional training: ….distinguish[ing] the professions from the sciences. Schools of engineering, as well as schools of architecture, business, education, law, and medicine, are centrally concerned with the process of design." The principal attribute of such professions is that they embark on the creation of the artificial, namely, achieving goals, to solve problems, by adapting the inner environment of the artefact (a product, system or process) to the external environment, which can be described as goal-seeking behaviour and attaining equilibrium i.e. an open system (Ackoff, 1971). Simon (1988) contends that, given the ubiquitous nature of design, and to differentiate it from the pure sciences that underpin it, then it should be treated as a science in its own right that should be taught and researched. This is very much in line with Dixon's thoughts (1966, p.9, 1987). Simon (1988) then lauds "systems engineering" as a discipline that has embraced the science of design.

Simon (1988) emphasises that the determining logic of design is very much a function of system complexity and how the system hierarchy may be decomposed into its constituent parts. Hence, bottom-up versus top-down, as well as inside-out versus outside-in, design logic will very much influence the final design outcome. But importantly, although Simon (1988) has a substantive discussion on utility and the role of optimisation he suggests that ultimately finding a satisfactory design, from a range of alternatives, is the expected outcome from the design process. Such a philosophy tallies with Jenkins (1969) in that an optimum design may yield a better utility than a satisfactory one but may be highly sensitive to uncertainties in system parameter settings. Therefore, the satisfactory design may be regarded as 'better', as the probability of instability, or tipping into chaos, is lower (Gardner & Ashby, 1970).

2.3 The design of research

Aken et al. (2016), building on Simon (1988), advance DSR, with its engineering roots, as a problem-solving oriented research method that ultimately yields an action, process or system that has been implemented and tested in the field. They suggest that the crux of DSR is a generic design which has universal applicability but also the power to deal with specific circumstances. Although Aken et al. (2016) do not explicitly deal with DSR research design they do note the classical engineering approach and cite two operations management examples from previous research, one being a "fictitious" deduction, wherein a simple method emerges that can be articulated as problem assessment, design development and field testing, with a potential cycle of redesign and test until the desired outcome is achieved.

Aken et al. (2016) note that there is a particular challenge in translating the DSR into operations management due to its engineering origins meaning that it is suited to technical problems, while operations management is predominantly dealing with socio-technical systems, and social scientists' unfamiliarity with the approach. Cross (2001 citing Rittel and Webber, 1973) warns that an engineering approach to the design of artefacts, as advocated by Simons (1988), deals with relatively 'tame' problems as opposed to 'wicked' problems that are often found in socio-technical systems.

Of course, problem solving in the social sciences is not an alien concept and there is a common process in creative problem solving (Voss et al., 1983, Tudor, 1992) although differences exist between the physical and social sciences (Voss and Means, 1989, Voss, 2005). In the former, problems, goals and constraints are generally, although not always, well-defined with well-established existing solutions to choose from while in the latter they are generally ill-structured and unprecedented, hence there are few historical analogous solutions. In both cases, the solution deriving process includes determining the goal of the problem-solving exercise and the transition from the problem state through various mechanisms of selecting alternative solutions, given specified constraints, to reach a goal state. A distinguishing difference between ill-defined and well-defined contexts is that the former takes relatively longer in the search for solutions. But solutions are nevertheless still required and the social science community is finding the need to engage across disciplines to undertake problem solving research to address the grand challenges faced by society (Brewer, 2013, Delbridge, 2014) with some suggesting that the systems approach has currency in that desire (MacIntosh et al., 2007).

Addressing the limitations of the artefact origins of systems engineering and coping with the complexity of management problems, soft systems thinking and soft systems methodology (SSM) emerged (Checkland, 1999), developed in response to the positivistic approach of Jenkins (1969) and has been proposed as an approach that allows social science business school researchers to engage with problem solving methods (Mingers, 2015). Contesting 'traditional' engineering, and classical operational research, notions such as goal seeking, optimisation and control, SSM follows Vickers' (1965) appreciative systems theory that sees the real-world as in perpetual temporal flux, where there is no exact repetition of events and relationships.

What SSM seeks to achieve is to define standards by which to judge real-world behaviours as desirable or unwanted that yields actions to maintain, modify or change real-world activity. Hence, SSM establishes a continuous learning cycle between observation, sense making (through models, such as rich pictures), judgement and action. Whereas the systems engineering perspective sees the real-world as systemic, soft systems thinking treats the learning cycle process as systemic. Interestingly, while Aken et al. (2016) give an example of a healthcare problem as an exemplar of how DSR may be applied in a social context, one of SSM's original applications was a national healthcare system (Checkland, 1999). And more generally, Parnaby and Towill (2008) show how good-practice changes made in the UK's National Health Service (NHS) may be attributed to approaches aligned to a systems engineering approach.

There are other examples where a more human centric healthcare design problem has been addressed from a systems perspective. For example, Towill (2006) and Brown (2008) determine how engineering design approaches, with a human-centric focus, are rooted in the well-known Kaiser Permanente, a non-profit healthcare provider, change management case, aimed at enhancing the quality of experience of both patients and healthcare staff. As with Checkland (1999), Brown (2008) stresses a whole systems perspective that is analogous to Vicker's (1965) appreciative systems principles. Instead of seeing change as a linear process, Brown (2008) speaks of multiple iterations of discovery, including prototyping, testing and refinement, within and through 'spaces', namely 'inspiration' (problem realisation), 'ideation' (synthesis of solutions) and 'implementation'. The 'ideation' space is where alternative designs are presented, as pictures / stories / scenarios, to bring order to what are seemingly chaotic situations.

Our final consideration in this section is the comprehensive treatise of the design discipline by Cross (2001) who articulates three different but related notions: 'scientific design', 'design science' and the 'science of design'. Cross (2001) states that the first, 'scientific design', is non-controversial and deals with the fact that design is no longer seen as merely a craft-form but has scientific roots, as we previously discussed with reference to Dixon (1966). Where there has been some previous discourse is in the meanings of, and debarkation between, 'design science' and the 'science of design'. The 'science of design' is more about design methodology and the scientific study of design itself, including ways of working, processes, technology and approaches. In contrast, 'design science' is "an explicitly organized, rational, and wholly systematic approach to design; not just the utilization of scientific knowledge of artefacts, but design in some sense as a scientific activity itself" (Cross, 2001).

Hence, we can see that to undertake DSR we need a strong foundational design methodology. The interest of this paper is the study of the design process and we formulate a generic DSRD that can form a platform for further research on methodological issues with respect to undertaking DSR. Building on the aforementioned narrative and observations of previous research, we may determine some distinguishing features of a problem-solving approach, rooted in engineering but with a firm recognition of the socio-technical relationship, relevant to logistics and operations management.

3. The need to revisit the systems approach to design resilient supply chains

The previous section reinforces the need for systems designers to select the right tools and techniques in relation to the situation at hand. However, which tools, techniques and methods should be used? The various methods and techniques outlined, such as system mapping exercises, mathematical modelling and optimisation routines, suggest relatively well-defined contexts where the human element is then relegated to merely a 'component' of the system. The advocacy of the SSM aims to overcome many of the limitations. But is SSM a panacea for all circumstances? Or are there elements of engineering techniques that may be exploited to advantage, perhaps in parallel with SSM?

There are several pitfalls in making the choice. First, there is a danger that the system designer selects tools and techniques that suit their own worldview and skills, rather than those that suit the problem. Second, there is the possibility that the situation changes, and different approaches are required. Third, despite the advocacy of holistic, systematic and contingent approaches to problem solving, with due consideration of the human, technical and process aspects in the design literature, there is a tendency to treat the people aspect with minimal consideration (e.g. in enterprise design Mertins and Jochem, 2005). There is often a drift towards technical optimisation, as this is more 'tangible' than people-based change e.g. changing worldviews or attitudes (Zhu et al., 2016).

Given the multifaceted nature of supply chain and operations management, at a whole systems level where there is interaction between the human, technical and process elements, system design problems are often described as complex (e.g. Miragliotta, 2011). Multi-disciplinarity is then promoted (e.g. Amer et al., 2010). There is also consideration of uncertainty. But the way such an attribute is addressed is predominantly by analytical methods wherein sensitivity and / or statistical analysis is undertaken (e.g. Kenné et al., 2012).

The systems engineering approaches desire controllability and predictability of the system and its interaction with the external environment. The ability to control ensures the system achieves its desired outcomes while forecasting allows for the system's future proofing as well as providing solutions for the present. The latter requirement is a challenge even in the design of engineering artefacts, such as major infrastructure, as there are extremely long lead times even from the concept through to the completion phase, let alone during the whole-life operation and subsequent end-of-life phase.

The tools and techniques to achieve the preferred system properties need to be extended beyond the purely 'scientific' foundations, which may have applicability in certain applications, and to encompass methods that have social science applicability. Nevertheless, problem solving via design is at the heart of the currently proposed approaches. The stages in systems design have applicability, especially that of the detailed explanation of Jenkins (1969), although with extension for explicit inclusion of an end-of-life phase.

We will explore the phases of the systems approach, including refining it for a more constructionist philosophy, in Section 4. In particular, we develop a generic DSRD based on a phenomenological framework known as Cynefin, Welsh for habitat, (Snowden, 2002, Kurtz and Snowden, 2003) that distinguishes between varying environmental domains, classified as Simple, Complicated, Complex and Chaos, wherein 'right-sized' management interventions are distinguished. Although the framework originates in the knowledge management field it has travelled to, and found relevance in, other disciplines including leadership (Snowden and Boone, 2007), healthcare (Fulop and Mark, 2013) and procurement (Alexander et al., 2014).

Cynefin (Snowden, 2002, Kurtz and Snowden, 2003) has resonance in engineering design practice. Naim et al. (2021) espouse the framework's relevance to the supply chain management of large construction engineering projects. Vollmar et al. (2017) relate the domains to design practice such that in the

- Simple domain existing standardised designs are exploited directly or adapted where there are routine or repeatable requirements,
- Complicated domain there is a reliance on engineers' experiences to deliver large-scale systems, for their whole life-cycle, with the aim of achieving optimum designs based on integrating existing technological solutions of the artefact being delivered,
- Complex domain unique designs have to be established for 'one-of-a-kind' systems. The uniqueness may arise due to several reasons, such as, different stakeholders involved in the system development, novel technologies or requirements that have never been previously articulated.
- Chaos domain there is a need to establish ways of dealing with unwanted scenarios to avoid this domain occurring or ensuring that an alternative domain exists.

We believe the domains are more nuanced than outlined by Vollmar et al. (2017), who very much focussed on the design of artefacts, and requires a more thorough consideration than just the spectrum of uniqueness through to commonality. Given that we are interested in going beyond artefact design and into supply chain design we question the relevance of optimisation as espoused by Vollmar et al. (2017).

The domains of the phenomenological framework may also be linked to the discourse by logistics researchers. As we introduced in Section 1, there are calls for greater methodological pluralism where until recently the positivistic approach, and the desire for optimality, has dominated (Gammelgaard, 2004, Darby et al., 2019, Wang et al., 2019).

The Simple, Complicated and Complex domains have some analogue with the 'analytical', 'systems' and 'actor' logistics schools of thought respectively suggested by Gammelgaard (2004). Nilsson and Gammelgaard (2012), building on the Cynefin framework, suggest that positivistic assumptions dominate the application of systems approaches in supply chain management research, and argue that different areas of complexity theory, namely complex adaptive systems (CAS) and complexity thinking (CT), are useful in guiding reflection and diversity in future research designs. They further argue that, given the dominant influence of positivism in the discipline, there is a need to reconsider approaches when research objects include people. Mingers and White (2010) suggest that CAS and CT are encapsulated in the general system approach as applied to a variety of operational research contexts including supply chain management. Similarly, Nair and Reed-Tsochas (2019) contextualise their study in systems theory terms. Nilsson and Gammelgaard (2012) further differentiate between CAS and CT, while in the Cynefin framework the Complex domain incorporates CAS (Snowden, 2002, Kurtz and Snowden, 2003).

Our perspective aligns with that of Mingers and White (2010) in that the domains may be incapsulated by the overarching systems approach and that the Complex domain incorporates CAS. We agree with Nilsson and Gammelgaard (2012) that perhaps there are discernible differences between CAS and CT and that there are overlaps between the domains with no hard boundaries (Snowden, 2002, Kurtz and Snowden, 2003). In particular, Nilsson and Gammelgaard's (2012) description of CT suggests that complexity and simplicity can coexist but cannot be 'designed', hence more synonymous with Cynefin's Chaos domain than any of the other three. Nilsson and Gammelgaard's (2012) CAS definition suggests overlap with Complicated.

Nilsson (2019) presents an aggregate model of logistics complexity that describes the assumptions made by a reductionist approach to management where at the highest level there is unorder and sociotechnical phenomena are observed, intermediate level supply chains and networks act as non-linear dynamical open systems and the lowest level there is order and elements may be decomposed into easily solvable parts. The systems approach is in contrast to reductionist thinking, providing an appreciation of how the individual parts work and the way they are integrated and synthesized to yield emergent properties by design, so that the component parts are in the context of the whole (Naim et al., 2019). Furthermore, reductionism entails taking a myopic, specialist disciplinary lens to a particular problem while the systems approach requires a multidisciplinary perspective with different skills being combined to solve the problem affecting the whole (Agazzi, 1978). While there are dangers that the whole is not considered and a default reductionist approach may result, this may be avoided by exploiting Cynefin as a frame of reference (Beurden et al., 2011).

Hence, we believe there may be a hierarchy whereby the Complex whole may be made of parts that are Complex, Complicated and/or Simple. Also, we can turn to the original framework and determine the correlation with a DSRD to designing solutions by determining the relevance of systems tools and techniques for each domain. The definitions and attributes of the different domains are articulated in Table 1. Each domain is different in character and there is a need for varying forms of interventions to solve problems, often in the form of events, circumstances or scenarios. Of course, it is not possible to precisely demarcate the domains and there may be opportunities to use a particular tool or technique, in addition to those specific for a particular domain, in more than one domain to enhance decision making.

Table 1 near here

We have included in Table 1 a column to indicate likely systems design principles, tools and techniques that may be appropriate in each domain and another column to gives examples of applications in logistics, supply chain and operations management It is noteworthy that there is little explicit consideration of the Chaos domain, as defined by Kurtz and Snowden (2003), Snowden and Boone (2007) and Vollmar et al. (2017), in the systems approach to problem solving. But what we do find is that many of the applications in the other three domains are attempts at avoiding going into chaos by enhancing supply chain or operational resilience or related capabilities, including robustness, flexibility, agility or leanness (Purvis et al., 2016, Adobor and McMullen, 2018).

Simple

Trappey et al. (2011) study the role of the servitisation process of a transformer manufacturer in ensuring the ongoing preventative maintenance of its equipment in a power generation plant. Exploiting business process reengineering and digital technologies, the solution to ensuring that the plant does not suffer catastrophic failure is a combination of condition monitoring and standard operating procedures. The latter is enacted via activity and object-based process system maps giving guidance to the human participants, cutting across functional boundaries, about their roles and actions required for particular events.

Dewan et al. (2013) analyse and critique a digital benchmarking tool that allows freight forwarders to compare and contrast their performance against others in terms of efficiency, effectiveness and environmentality. The benchmarking process is an example whereby the assumption is that 'best practices' may be identified and replicated, and targets set, to ensure continuous improvement of an operation and/or its supply chain.

Hozak and Olsen (2015) gives various examples of lean techniques, as applied to manufacturing systems, that attempt to establish simple rules or heuristics to ensuring safe and efficient operations. An example given is the 'andon' cord / light, whereby if quality or other problems are identified then the production lien is stopped to enable solution to be found. Here is an example where a standard operating procedure is developed to ensure that the system does not potentially tip into chaos but allows the human participants to 'stop and think' to identify the root cause of a problem and find the right solutions.

Complicated

Wang et al. (2012), research mathematical notions of chaos based on a system dynamics analysis of inventory control system archetype (Lin et al., 2017), an outcome of human derived decision rules, account for transport / manufacturing delays and system structure, that have been automated . Such approaches explore the dynamic properties of a system and determine when a system may be stable or unstable, and if the system shows periodicity, quasi-periodicity or chaos. The resultant methodology is a means to avoid becoming chaotic.

Tako and Robisnon (2012) undertake a comprehensive review of academic literature exploiting discreet event and system dynamics simulation to support decision makers in designing and executing logistics and supply chain management systems. They conclude that such simulation approaches are pervasive with the derivation of solutions associated with strategic, tactical and operational decision-making including supply chain structure, information transparency, addressing the bullwhip effect, inventory management and transportation planning.

Spiegler et al. (2016) exploit non-linear control engineering with system dynamics simulation to determine the resilience capabilities of an automated production planning and stock control system in a grocery sector distribution centre. They analyse the system's response to one-off shock disturbances, noise, in the form of stochastic uncertainty, and cyclical inputs. They suggest managerial interventions based on previous known solutions on analogous theoretical models and empirical contexts.

Complex

Choi et al. (2001) consider the supply chain as a CAS. They suggest that such systems have self-organising behaviours that yield emergent properties. They need capabilities, including adjusting goals and infrastructure, to maintain degrees of freedom to respond to quantum changes and avoid the system tipping into chaos. This is in line with Checkland's (1999) social science-based philosophy to interventions in the 'complex' domain.

Undertaking case study research in the food and steel sectors, Wang and Lalwani (2007) utilise the soft system methodology to determine how e-business may support different relational models for logistics companies to offer sustainable customised services. They judge the performance of the various forms of working based on qualitative judgements of their efficacy, efficiency and effectiveness. Their 'soft' approach allows for the selection of the appropriate relational forms for each case company since they are perceived to be satisfactory rather than optimal.

Day (2014) shows the exponential increase in disaster relief programmes in the USA and the lack of adequate responses to such disturbances. Day (2014) argues the need for the supply network supporting disaster relief to be conceptualised as a complex CAS with resilience as the primary the emergent property.

Powell et al. (2018) undertakes systems analysis that explores risks, prevalent in crises management research, and the means to mitigate such risks. They provide a hybrid human activity (soft systems) / systems dynamics approach to understand what the risks are, and ways to avoid or minimise those risks, in anticipation of a potential disaster event.

Ultimately, the challenge for the system designer, and the multidisciplinary design team, is to determine in which domain the problem resides and to ascertain whether the problem can be solved by remaining in that domain or if there is a need to transfer to another domain to achieve the desired standards / goals of the system. The transference may not be direct but could entail a 'journey' through one or two other domains. There is a fifth domain, described as 'disorder' wherein there is ambiguity and indecision, or a lack of consensus, as to which of the other four domains the situation faced is placed in (Kurtz and Snowden, 2003) and we would extend to include the solution space. There are potential dangers in selecting the wrong domain or being in 'disorder' as the application of the wrong tools / techniques could mean deriving the wrong solution. We outline how our thinking relates to the design of a supply chain system and how tool selection may play out in such a scenario.

4. Systems engineering and the development of a generic DSRD for supply chains

Table 2 shows the determining phases of systems design from examples of different disciplinary and application areas, indicating the pervasive nature of design thinking both from academic and practitioner perspectives. They have common elements that can be the basis for a generic DSRD. Jenkins' (1969) stages include the implementation and operation of the new design. Parnaby's (1991) reengineering stages are a rearticulating of the original manufacturing systems design approach (Parnaby, 1979). The UDSO (Watson, 1994) and ASIA (Small, 1983) give examples of design phases advocated by the Boston Consultancy Group and Ingersoll Engineers respectively. Also given are the design phases for information technology / systems implementation (Jacobson et al., 1995). Finally, although remembering that the ethos is quite different, we have included Checkland's (1999) learning cycle and Brown's (2008) design spaces.

Table 2 near here

A common feature of all approaches is that there is a fundamental need to understand and articulate the problem being addressed. We argue that this first step is critical in determining which Cynefin domain the problem resides in requiring consensus among the multidisciplinary design team. Given that supply chains, logistics operations and manufacturing systems are inherently complex, consisting of people, machines and processes, with multiple entities and flows, then at the highest level the starting proposition, from which the team may agree to digress at a later stage, is that the problem is in the Complex domain.

To show the possible application of our thinking let us take an established supply chain design method. Figure 1 shows the framework from Naim et al. (2017), adapted to include analogical reasoning from an original concept developed by Naim and Towill (1994) that has itself been exploited by others, such as in the design of supply chains in waste management to accommodate the impact of new regulations on the social inclusion of operatives (i.e. a focus on people) (Ghisolfi et al., 2017), the closed-loop automotive industry supply chain in Japan to ensure efficiency of resources with changing end of life requirements (i.e. a focus on process) (Kumar and Yamaoka, 2007) and the grocery sector to enhance the resilience of an automated replenishment system (i.e. a focus on technology) (Spiegler et al., 2016). The common aspect of the aforementioned papers, despite their different foci on people, process and technology, is that they apply control theory mathematical modelling and/or system dynamics simulation to analyse and synthesise production ordering and inventory control to minimise system variance and hence production on-costs and inventory / backlogs costs. Therefore, they are very much designing based on the assumption of being in the Complicated domain.

There are various phases incorporating both qualitative and quantitative approaches. So, what we have done with Figure 1 is to superimpose on the left-hand side the various domains that the method transitions based on the specific techniques applied and their purpose. And, given that the format of Figure 1 suggests a linear process, to show the iterative nature of the problem-solving approach we have superimposed the design thinking's spaces (Brown, 2008). At the outset, there is recognition of the real-world's complexity, hence there is a need to define the problem and what is to be achieved by the design process. The design team may select the appropriate soft systems principles, tools and techniques given in Table 2.

In the case of a production planning and control, the problem and solution domains are residing in the Complicated domain. This is based on the premise that the control systems are automated and algorithmic. But where there is human interaction and intervention in the ordering rules and inventory policies (e.g. Syntetos et al., 2016) then the problem domain still resides in the Complex domain although there may be a desire to minimise human decision making so that the solution will ultimately be a fully automated system for the majority of the products for the majority of the time with human intervention only to deal with exceptions. Such interventions require protocols or heuristics to guide human judgement (Parnaby, 1979).

Naim and Towill (1994) advocate the use of input-output diagrammatical models for helping in the analysis of the current system state. This is in line with Parnaby (1979) who saw input-outputs models as the organisational equivalent of a circuit diagram that aids electrical engineers to diagnose the current state of on electrical system. Conceptual models can be in the form of causal loop diagrams as advocated by the System Dynamics movement (e.g. Iannone, 2015, Richardson, 1997). We also strongly advocate the exploitation of rich pictures (Checkland and Scholes, 1999, p. 45) and CATWOE analysis (Checkland and Scholes, 1999, p. 35) at the outset, priori to using the aforementioned input-output and causal loop diagrams as the former techniques allow for a greater appreciation of the varying political discourses and cultural contexts that define the domain in which the problem resides.

In any case, such visual models, as with any type of model whether narrative, simulation or mathematical, are simplifications of the real-world so we are actually transforming the real-world situations from the Complex domain to a 'synthetic' Simple / Complicated domain to allow the design team, and all stakeholders, to 'see the wood for the trees'; identifying key variables, actors, activities and issues that govern the behaviour of the current system. Therefore, there is a need to continuously relate back and forth between the synthetic and real-world while progressing along the framework to ensure model credibility, as seen by the stakeholders, as opposed to just verification or validation (Towill, 1996).

The framework of Figure 1 then proceeds to develop control engineering block diagrams, control theory transfer function formulations, statistical, or stochastic, mathematical forms and computer simulation. These may all be classified as being in the Complicated domain as they determine cause and effect relationships with lags that represent temporal delays and spatial distances in the real-world. Figure 1 also shows an addition to Naim and Towill's (1994) original framework by the addition of an analogical reasoning heuristic that allows the design team to relate the current problem, or 'target model', to be compared to apposite previous experienced problems, or 'source model', from which a possible set of 'candidate solutions' may be identified. We should note that the outcome of the simplification procedure, as given by Naim et al. (2017), is a *simpler* block diagram representation, making it easier to compare and contrast the 'target' and 'source' problems.

Hence, the design or synthesis phase of the framework remains in the Complicated domain. Multiple solutions may be defined represented in Simple domain form so that decision makers can make informed choices regarding the benefits and costs of each. This shows an appreciation that, although the designs may have been derived optimally from an analytical perspective, based on criteria and metrics established at the problem definition stage, when exploiting the solutions there are considerable Complex trade-offs to be considered and hence the need to derive satisfactory alternatives.

"Most human decision-making,….. is concerned with the discovery of satisfactory alternatives; only in exceptional cases is it concerned with the discovery and selection of optimal alternatives." (March and Simon, pp. 140-141, 1961)

For example, Naim and Towill (1994) suggest simply tuning the parameters in a production planning and control system can have desirable outcomes. This would simply entail changing a value by recoding some software, in essence, a Complicated domain activity that can yield an optimum solution. But this optimal solution would be one of a series of satisfactory alternatives. One 'structural' design that would potentially greatly enhance the supply chain's ability to deliver products on-time, in-full and at minimal cost, according to the analytical synthesis, would entail bypassing / eliminating whole echelons, with ramifications for the viability of those businesses being removed with consequential political, cultural and legal ramifications. Clearly, such a solution would be in the Complex domain and require a considerable change programme in the real-world.

Figure 1 near here

5. Some reflections and research challenges

5.1 The origins of the problem and solutions

Much of the engineering design literature is obviously focussed on product introduction / development. Hence, we find that the problem is driven my market opportunities and / or technological development, which then drive (re)design of the product itself requiring a (re)design of the manufacturing process, although there is a realisation that constraints require a cycle of evaluation and revaluation between all stages (Dixon and Duffey, 1990). Jenkins (1969) is more focussed on the organisation, typically a manufacturing plant, where managers have problems that need addressing. Parnaby (1979) while also addressing manufacturing systems design is more explicit in recognising the impact of market changes and / or product design on the manufacturing process and is synonymous with Dixon and Duffey's (1990) problem drivers. Contemporary research (e.g. Schoenwitz et al., 2017) suggests that the problem definition stage needs to encompass the different problem drivers for change, which could be related to the product and / or the manufacturing system, or sub-systems thereof, led by market changes (what customers want) or technology (for the product itself, or related to manufacturing e.g. machines) but also ways of working (processes, producers and protocols / heuristics).

While a criticism of the systems approach is that defining boundaries excludes external stakeholders and restricts realisation of potential change solutions (Stacey et al., 2000, p 78), the Cynefin framework drives behaviours so that external stakeholders become engaged actors in the system under study (Naim et al., 2021). The 'soft' system approaches (Checkland, 1999, Brown, 2008) have more holistic perspective, looking to find out where the problem arises, from many different viewpoints. These are particularly pertinent in the Disorder domain for problem definition in 'messy' situations found in logistics and supply chains especially with respect to the complex domain with example applications given in Table 1.

5.2 Hierarchical considerations

While Nilsson (2019, citing Stacey, 2000, p. 326) argues that "there are no levels separating the interacting groups of people" he does suggest the need for "more multi-level research" as per Carter et al. (2015). Carter et al.'s (2015) levels are based on a hierarchical nesting of individuals within teams, teams within functions, function within organisations that then reside within supply chains. The system hierarchy we propose requires due consideration of people (individuals with their attitudes and behaviours) but also due consideration of their interactions with other elements such as processes and technologies that together may create complexity.

The term complex itself "refers to a system that is composed of interrelated subsystems, each being, in turn, hierarchic in structure" (Hussein et al., 2014). Thus, Complicated systems are a special case of Complex ones (Allen, 2000, Poli, 2013). In exploiting the Cynefin framework, a system in the Simple domain may itself be a sub-system of a system that can be in the Simple, Complicated, Complex or Chaos domains, a system in the Complicated domain can be sub-system of a system in the Complicated, Complex or Chaos, while a system in the Complex can be a sub-system of a system in the Complex or Chaos domains. A system that is in the Chaos domain will exist in its own right and is a result of having undesirably transitioned from one of the other domains.

For example, we may find that a make-to-stock factory has processes that can be analysed and synthesised in the Complicated domain. The manufacturing processes may have operations or machines that can be defined in the Simple domain, but the factory is itself an organisation and a part of a supply chain, that is best considered in the Complex domain. Or we may find that the factory is in an engineer-to-order environment, whereby products are designed on a 'one/first-of-a-kind' basis from first principles and the manufacturing operations have to be uniquely developed, with specialist operators' skills, to produce the final products. Hence, we may find the system and all its levels are complex. At any point in time, say due to a supplier insolvency, due to a financial crisis, or a catastrophic event, say, a hurricane or tsunami, that renders the factory incapacitated, then the system will tip into the Chaos domain.

We therefore find that we may decompose a Complex system into its individual sub-systems that may be designed according to which domain they are each in as per the tools and techniques of Table 1. But ultimately, there is a need to design the whole and that should be treated as a system in the Complex domain.

Therefore, we suggest consideration of iterative models of artefact development, from design through prototyping and testing to implementation, as templates for socio-technical system problem solving. For example, there is the well know 'V-model' of systems engineering (e.g. Cavalieri and Pezzotta, 2012, Stevens et al., 1998, p. 8) whereby whole system requirements are decomposed into individual part requirements, which are then implemented and integrated to produce the final system, may be considered as a potential model that has found favour in large-scale software project applications.

5.3 Criteria and metrics to judge outcomes of the design

While the various example references in Table 1 will give due consideration of various metrics exploited in logistics and supply chain management, including cost, time, flexibility, reliability, quality, sustainability (Dewan et al., 2013) and efficiency, effectiveness, and efficacy (Wang and Lalwani, 2007), the hierarchical concept allows different parts of the whole to be designed according to different criteria. Checkland (1999) proposed that, as well as efficiency, effectiveness and efficacy, there is a need to consider ethicality and elegance. Elegance is a consideration in product design but so too is ethicality (Dixon, 1966). We could also introduce notions of environmental considerations. Hence, we find that concepts of public value in the social sciences (Brewer, 2013) are coming to the fore and end-of-life considerations need also to be addressed. Hence, it is easy to see why then, taking multiple criteria together, formulating a utility that can be optimised becomes increasingly intractable. Satisfaction and appreciation trump goal seeking behaviour as the problem definition and solution escalates in the system hierarchy.

5.4 What do we do about the Chaos and Disorder domains?

We have deliberately not dwelled on the Chaos domain as it is highly unlikely that you would design a supply chain system to be maintained and operated in such an environment! As we have previously noted, existing systems approaches attempt to avoid entering the Chaos domain. Parnaby (1979) highlights that a manufacturing system needs to be designed to ensure "long-term stable operation" despite "continually changing constraints and external disturbances". Naim et al. (2004) note that supply chains that are increasingly complicated or complex, with more nodes and variables, are more liable to 'tip' into unstable dynamic behaviour unless adequately designed. So we may find that if a supply chain has been designed with inadequate principles for the domain it resides in then the outcome may be either inefficiency of an 'over engineered' design or failure (Cowper et al., 2014), with the latter liable to transitioning the supply chain into 'chaos'.

Alexander et al. (2014), while noting the lack of supply chain research into the Cynefin Chaos domain, point to the need for supply chains to be resilient to disturbances, such as a financial crisis or world-wide pandemic, to avoid becoming chaotic. Hence, we find a dichotomy between efficiency of design and building in redundancy, one of the capabilities required to ensure resilience to be exploited with others, such as agility and flexibility.

So, there is much more research required, both conceptual and empirical, to fully understand what are the underlying capabilities, and how they are to be exploited and intertwined, to ensure resilient supply chain design (Purvis et al., 2016, Messina et al., 2020) in order to either avoid a supply chain going into chaos, where there is already foundational research, or making sure that if it does become chaotic it then recovers quickly and fully into its desired domain.

Hence, there is a need for a new systems approach to dealing with the Chaos domain. As we have indicated, the existing logistics and supply chain research methodologies dominate in the Simple, Complicated and Complex domains with little methodological considerations of how to apply a DSRD in the Chaos domain. Similarly, dealing with Disorder has been given limited attention (Naim et al., 2021) although it is in this domain where there is potential to ensure diversity of ideas, collaboration among actors and multi-ontology perspectives (Fulop and Mark, 2013).

5.5 Towards an integrated perspective and future research agenda for the design of resilient supply chains

From the foregoing discussion it is possible to see that there are a wide range of approaches that can contribute to logistics and supply chain design. In the face of new technological frontiers in data analytics, Internet of Things and Industry 4.0, combined with the varying social, economic and environmental disturbances faced, there is a need to determine which specific approaches to use in different situations. Various approaches have evolved through different disciplinary lenses and lacks an integrative framework.

We believe the Cynefin framework has methodological credence by which to provide a construct to not only integrate the approaches but also to determine which approaches are right for the problem situation. In addition, it offers the opportunity to collectively pull problem solving individuals and teams towards consensus and collective sensemaking. Hence, we arrive at a new perspective in terms of 'design' acknowledging the role that system design can play in complex socio-technical supply chains.

We propose a system 'V-model' for the design of resilient logistics and supply chains as shown in Figure 2 with the following propositions:

1. A 'soft' system approach used by an interdisciplinary team will enable a holistic, multistakeholder, definition of the problems faced, allow for due consideration of internal and external factors, and will provide a mechanism to avoid the Disorder domain.
2. Identifying and accommodating different hierarchical levels will lead to the decomposition of the problem into the appropriate hierarchical level and hence the right unit of analysis and system boundaries.
3. The right unit of analysis will determine the Cynefin domain specification for each so that the selection of the right tools and metrics to design and implement a solution may be determined.
4. Cynefin will enable the integration and recomposition of the various 'parts' of the logistics systems and supply chain.
5. In the Chaos domain exploit an alternative form of the 'soft' systems design thinking in Table 2 to transition into the Simple, Complicated or Complex domains
    a. Ideation – design and choose a solution
    b. Implementation - of the chosen solution
    c. Inspiration – determine if the action was successful, if not, go back to Ideation until you are out of the Chaos domain

Figure 2 near here

We suggest a pluralistic methodological approach for future research to test, adapt and enhance the above propositions. And such a pluralistic and integrative approach has a defined pathway for undertaking the research, in terms of breadth (the different Cynefin domains and associated interdisciplinary tools and techniques) and depth (structured systems design science research methods). As noted by Mentzer et al. (2004), a unified theory of logistics would provide benefits for both logistics researchers and practitioners. Hence, based on our line of reasoning, a well-considered DSRD, taking into account a pluralistic and integrative approach, can help to move towards this position as it overcomes the potential pitfall of a lack of research norms that may be found with adhoc pluralism that inhibits the logistics and supply chain field in progressing as a 'science' with a well-established theoretical base (Chicksand et al., 2012). We also believe that our suggested systems-based approach provides a cohesion and consistency to the intervention-based research process for theory testing and development as proposed by Olivia (2019), which is founded on Checkland's learning cycle. And that we can cope with the 'messes' found in complex systems i.e. the interwoven systemic problems that exist and not just focus on any single one (Ackoff, 1994), thereby addressing the wickedness of only addressing a single 'tame' problem in isolation that leaves underlying systemic problems to proliferate (Churchman, 1967).

6. Conclusions

We have shown that there already exists a foundational and comprehensive body of knowledge that articulates the application of DSRD from both an engineering and social science perspective. The systems movement, consisting of a portfolio of methods and tools, ranging from systems engineering through to soft systems thinking, that are continuously being improved and renewed, allows for a contingent approach to DSR. Hence, our generic DSRD allows for the selection of the most appropriate techniques, to be adapted or developed as need be, for the design of resilient and sustainable supply chains, dependent on which domain of the Cynefin framework the problem resides. It should be appreciated that the final outcome may be the result of various translations of the original problem definition through multiple domains during the design process life cycle.

Our research identifies various future research challenges. These include the determination of the source of the problem, say whether due to changing product requirements, legislative forces, or advancements in manufacturing processes, and how that impacts the foregoing design process method. DSR can come to the fore here as part of the problem definition stage of a systems approach.

There is also the issue of how best to address hierarchy; given the supposition that the whole is greater than the sum of the individual parts, how can we best decompose a complex supply chain problem into a meaningful simple solution that when reintegrated ensuring the whole satisfies desired behaviours? Again, we believe that DSR has a role here especially through co-created, co-designed empirical research by multidisciplinary teams of academe and practitioners.

While we believe that a DSRD is well catered for in the Simple, Complicated and Complex domains of the Cynefin framework, dealing with the Chaos and Disorder domains is a major gap in existing systems approaches to supply chain problem solving. While existing tools and techniques are laudably developed and exploited to avoid the Chaos domain, there is a need to establish an explicit systems approach to the design of supply chain management interventions should the supply chain find it is in Chaos. We believe that a fundamental synthesis of such an approach is possible by undertaking a metanalysis of previous crisis management research. Testing of the new approach may be then undertaken via DSR.

There is also much to do with respect to the Disorder domain. Identifying the right domain and the various paths through them to develop a viable solution sounds intuitively appealing but practically there are no explicit tools and techniques to aid logisticians and supply chain managers. This is especially concerning given the potential for designers to resort to their comfort zone and researchers to try to force the problem into their preferred philosophical stance. We believe there is merit in further research to overcome such pitfalls and develop a means to navigate the resulting discourse within a multidisciplinary team thereby avoiding the pitfalls of reductionism.

We believe all the foregoing contributes to the logistics and supply chain community. It is a reminder that, despite the seemingly 'new' challenges we face that we need to find solution to, there are underlining tenets that provide a template for researchers to exploit and adapt especially with respect to systems approaches to research design. Hence, we are not dependent on starting from a blank sheet of paper or 'reinventing the wheel'. We suspect that even the proposition we give in Section 5 may exploit knowledge and learnings that have been instrumental since the original conceptualisation of General System Theory and the methodological plurality that resides within. And that the Cynefin framework enables a structured execution of methodological selection and integration.

Acknowledgments

We thank the Editor in Chief and the anonymous reviewers for their comprehensive engagement with the paper, giving detailed and constructive critiques during various rounds of review. Their challenging has allowed us to reflect on our own thinking and encouraged us to extend the literature hence greatly enhancing the depth and reach of our paper. We hope that the paper provides a platform for not only our own future research but also that of others. Also, we do not claim the paper to be definitive but rather hope to encourage debate and collaboration within our logistics and supply chain community as the world we live in seems to be ever more fractured and close to tipping into 'chaos'.

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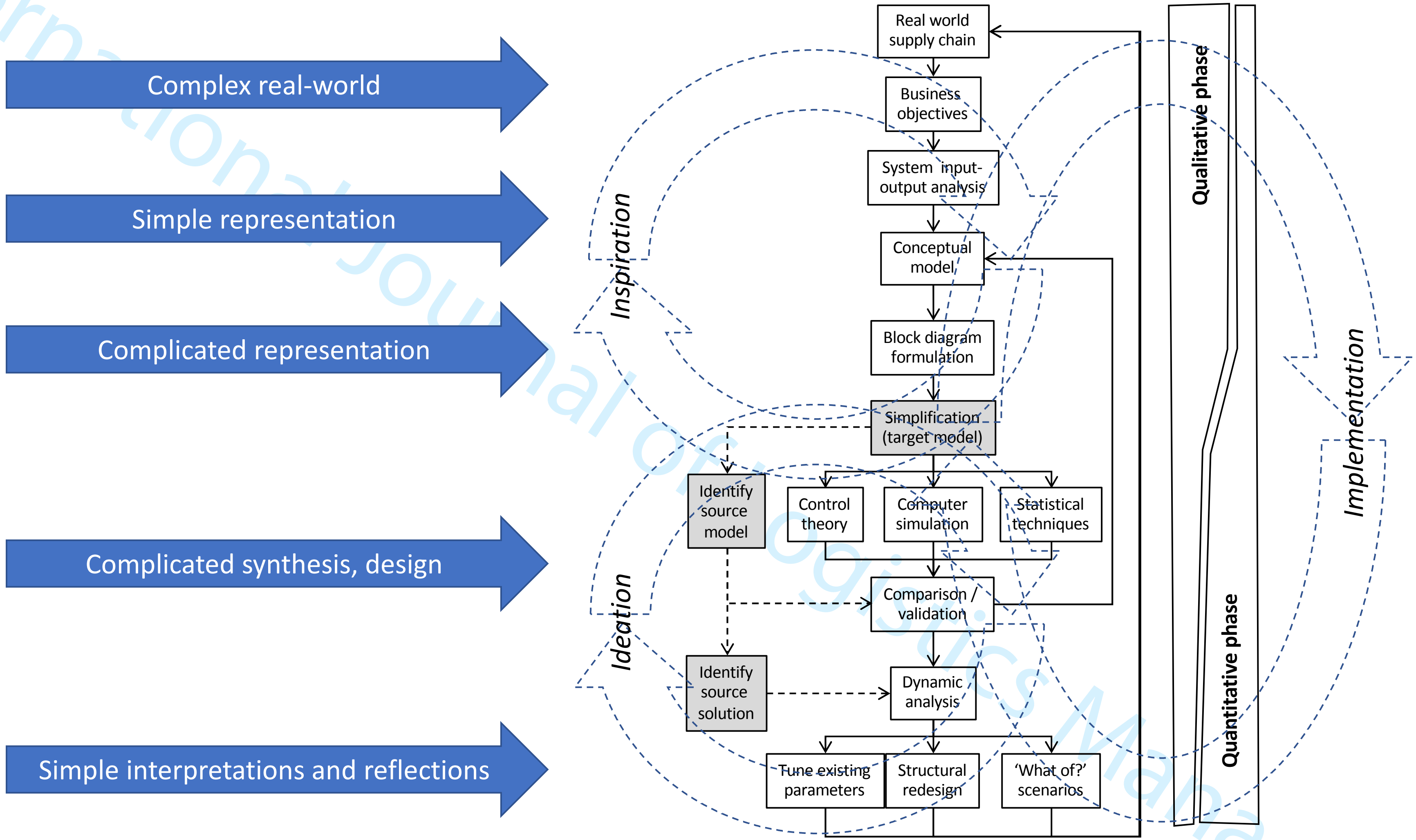

Figure 1: A schema for supply chain design to mitigate the bullwhip effect (Naim et al., 2017 based on Naim et al., 1994)

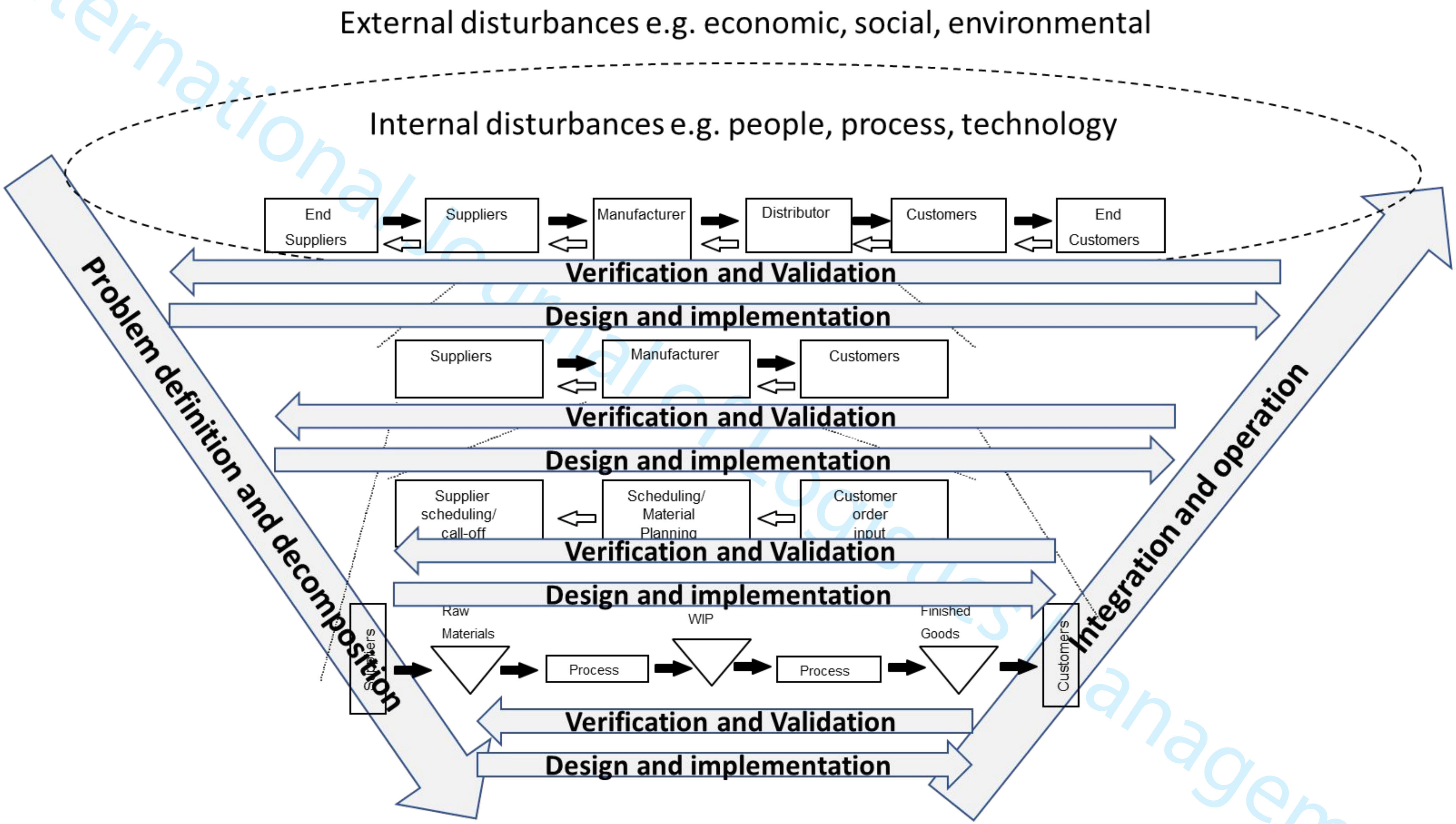

Figure 2: Systems design of the resilient supply chain (Authors: based on the 'V'-form of life cycle e.g. see Stevens et al., 1998, p. 8)

Domain	**Explanation** (based on Kurtz and Snowden, 2003, Snowden and Boone, 2007, Vollmar et al., 2017)	**Systems principles, tools and techniques** (based on Naim et al., 2019, Checkland, 1999, Towill, 1991, Maani & Cavana, 2007)	**Example applications**
Simple	- It is easy to determine, model and forecast cause and effect relationships. -Sense making is exploited to understand the internal and external environments. - Classic classification techniques may be adopted, and responses designed to meet all existing and forecasted circumstances, or problems. (e.g. standard operating procedures, best practices and benchmarking). - Static quantitative techniques are exploitable here. - Established design solutions can be reused or adapted.	- Predicated on 'facts', deterministic tools and techniques can be used. - Models can be developed based on well-established laws or theorems, assumptions and grounded on quantitative empirical data. - Classic operations research techniques, such as stochastic modelling, queuing theory and linear programming, are applicable. - Industrial engineering tools may also be exploited, including process mapping, input-out diagrams, structured analysis and design technique, cause and effect, Pareto / ABC categorisation. - Objective functions may be defined, and optimisation routines establish solutions.	- Trappey et al. (2011) establish a novel standard operating procedure to avoid the total shutdown of a power generation plant - Dewan et al. (2013) establish an online benchmarking tool for freight transport organizations to set improvement targets based on best practices - Hozak and Olsen (2015) suggest that systems thinking rules provide best practice guidelines for workers to trigger an 'andon cord' when quality issues arise and prevent a production system becoming 'chaotic'.
Complicated	- Relatively easy to determine, model and predict cause and effect, although they are separated by time and space. - Sensing methods are still exploited with data gathered and assessed to established easily forecastable scenarios, or problems, for which responses are established. - Domain dynamic modelling approaches are appropriate. - Opportunity exists to draw analogy with previous problems, amalgamate / adapt designs and / or look for novel means of implementation in potentially new application areas.	- Opportunity to utilise both qualitative and quantitative approaches. - Possible to exploit control engineering mathematical models (continuous or discrete time form, linear and non-linear), both in terms of block diagrams and transfer functions to analyse time lags and feedback loops. - Models and simulations that replicate dynamic behaviours, such as in System Dynamics, can be developed to ask 'what if?' questions. - Optimisation is not a realistic proposition here although multi-attribute utility methods may be adopted. - Observability and controllability are system requirements that can be addressed.	- Wang et al. (2012) exploit a control theoretic model to determine the stability of a generalized production planning and inventory management ordering rule to avoid the system entering 'chaos' - Tako and Robinson (2012) highlight the ubiquitous application of discrete event and system dynamics simulation in designing a range of supply chain related. - Spiegler et al. (2016) exploit non-linear control engineering techniques to determine the resilience characteristics of a grocery supply chain

Complex	- Cause and effect relationships are observable but only after they occurred. Behaviours and patterns emerge but there is a lack of repetition and they are not predictable. - The environment needs to be continuously probed to make sense of the situation and determine responses. - There is a need to capture different perspectives of the same situation from different stakeholders, in the form of narratives, to probe our environment and understand the situation - Quantitative techniques are of little benefit in this domain. - Narrative forms aid with the probing and sensing. - Opportunity to learn from previous similar case studies, exploiting analogical reasoning, in this domain there may be unique attributes that requires a high degree of innovation.	- Organisational theory underpins the potential systems methods in this domain, requiring explicit and thorough deliberation of people and how their social interact within an organisation structure. - Opinions and perceptions are the primary considerations. - Narrative forms (e.g. stories, myths and pictures) are the means by which people can communicate, probe, sense and understand. - Systems Thinking, such as SSM, including 'rich pictures' visualisation modelling, CATWOE analysis, influence diagrams and causal loop diagrams are more applicable.	- Choi et al. (2001) suggest that, to avoid tipping into chaos, purchase managers should conceptualise their supply networks as complex adaptive systems that 'emerge' rather than an outcome of a goal seeking design - Wang and Lalwani (2007) use soft systems techniques to determine the efficacy, efficiency and effectiveness of an e-business model to delivered customized and sustainable logistics provision in the steel and food sectors. - Day (2014) conceptualizes a complex adaptive supply network to mitigate against disasters. - Powell et al. (2018) combine soft systems thinking and systems dynamics approaches to establish a risk management framework in preparation for a potential flooding disaster.
Chaos	- This domain is unwelcome, and cause and effect relationships are not apparent in this domain. - There is little time to analyse so that when a specific event, or problem, occurs then there is a need to act first, sense the outcomes of the actions and then decide on what additional actions are required. - Crisis management is used in this domain, with the tools and techniques deemed useful for the other three domains deemed insufficient here.	- The goal here is to move out of Chaos and relocate into another domain as quickly as possible. - No explicit systems tools and techniques identified in the literature.	- Machine breakdowns on a production line stops output - Humanitarian disaster relief due to flooding or an earthquake - Financial crises leads to suppliers going bankrupt - Pandemic impacts demand, and hence availability, of protective personal equipment

Table 1: 'Right-sized' systems approaches for different problem domains

Systems engineering stages (Jenkins, 1969)	ASIA stages (Small, 1983)	Manufacturing systems reengineering stages (Parnaby, 1991 developed from Parnaby, 1979)	Business systems engineering stages (Watson, 1994)	Information systems reengineering stages (Jacobson et al., 1995)	Learning cycle stages (Checkland, 1999 based on Checkland, 1972)	Design thinking 'spaces' (Brown, 2008)
1. Systems analysis 2. Systems synthesis, design 3. Implementation 4. Operation	1. Analyse 2. Simplify 3. Integrate 4. Automate	1. Market analysis 2. Business process analysis 3. Steady state design 4. Dynamic design 5. Information and control design and system integration	1. Understand 2. Document 3. Simplify 4. Optimise	1. Envisioning 2. Reverse engineering 3. Forward engineering	1. Finding out about a problem situation 2. Formulating purposeful activity models 3. Debating the situation 4. Action	1. Inspiration 2. Ideation 3. Implementation

Table 2: Systems approaches to problem solving