GUEST EDITORIAL

Some thoughts on interdisciplinarity in collaborative networks' research and manufacturing sciences

Hermann Kühnle
IAF, Otto-von-Guericke University Magdeburg, Magdeburg, Germany, and
Rob Dekkers
UWS Business School, University of the West of Scotland, Paisley, UK

Abstract

Purpose – Scientific progress in a field is mostly discussed within disciplines. Far less attention is paid to outside or between disciplines' work. To speed up research progresses for collaborative networks (CN) in manufacturing, a base for further grounded theory establishment is propagated, recalling some of the most relevant chapters of philosophy of science. The focus is put onto the roles of disciplines and their scholars involved in interdisciplinary contexts, in order to further motivate as well as to hint at a number of catalysing forces and fruitful impacts of outside disciplines' work.

Design/methodology/approach – The intentions of this Special Issue are mirrored to important and well-accepted findings in the philosophy of science. All papers that are included in this journal issue are positioned within a general framework of scientific disciplines and theory building understanding.

Findings – Interdisciplinary work is speeding up theory building and innovation in CNs in general and in all applications for manufacturing in particular. In order to encourage publications of project work and solutions that do not neatly fit into the scientific disciplines set up, it is pointed out that exactly these papers have the potential to unveil unattended and valuable insights. This kind of outline often confirms both gut feelings of managers, as well as vague hypotheses of researchers and scientists.

Research limitations/implications – The paper shows that more attention might be paid to outside contributions and to mechanisms to increase their impact on theory building in manufacturing science.

Originality/value – For the field of CN, the paper represents a first and unique attempt to enhance scientific progress by emphasising theory contributions from other disciplines. The approach contributes to theoretically as well as methodically supporting the fast growing number of practical solutions beyond state of art.

Keywords Manufacturing industries, Sciences, Research methods, Philosophy of science, Theory building, Scientific disciplines

Paper type General review

In search for competitive excellence in manufacturing, collaborative networks (CNs) have received much attention during recent years. Understanding and anticipating on network characteristics in "product design and engineering"[1] and manufacturing creates potentially competitive advantage for the firms that participate in those CNs. However, concepts for CNs, typologies and enabling software have generated mostly isolated solutions to problems so far. Large portions of the acquired knowledge about CN

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are cast into rather singular models or solution-oriented procedures uniquely based on case experiences and anecdotal verifications that need further validation to establish their scope beyond instances (see Wacker, 1998 for how theory is formed in operations management). These phenomena will even become more manifest since major trends in manufacturing are distributed organisational and geographically dispersed structures (Kuehnle, 2007), more loosely coupled entities for industrial networks (Dekkers and Bennett, 2009) and fragmentation of manufacturing and control processes (Kuehnle, 2007). Hence, we posit that incoherent approaches originating from these different aspects have led only to heterogeneous and inconsistent fragments for consolidated knowledge about CNs or for underpinning theory.

At the very same time, there is an ongoing debate concerning the nature of theory necessary for manufacturing networks, especially footing on CNs. The once clearly defined domain of manufacturing science has to recognise that only increasingly contributions drawn from other disciplines might ensure more commanding generic concepts, models or theoretical approaches for CNs. Among the eligible disciplines that might make a worthy contribution we enumerate theory from complex adaptive systems, decision sciences, evolutionary biology, game theory, organisational theory, sociology and topology, alongside more traditional approaches from data exchange and network management. Within the narrower scope of management sciences, network management has established itself as a field for CNs. And concepts from data exchange are seen as relevant to structured communication protocols. But within all these disciplines and fields attempts have been made to investigate and to describe phenomena of collaboration in networks and related changes that are taking place in industrial entities. However, to-date there has not been published an edited, collective account of the different perspectives that exist among the various academic and industrial research communities towards the new science that might emerge, even though Camarinha-Matos and Afsarmanesh (2005) have called desperately for furthering insight; this special issue aims to remedy this gap.

1. Collaborative (manufacturing) networks – stuck between disciplines?

Rien ne va plus – Anything goes.

But even though the contributions of the special issue aim to fill this void, one imperative question beyond the state-of-the-art for researchers as well as managers working with and within company networks emerges: what direction will manufacturing and management science take within this setting of networks? That requires looking first at where manufacturing science came from. Since the 1990s, manufacturing science and management have been advancing at fast pace, echoing Buffa's (1980) call. After the propositions of Skinner (see Dekkers and Bennett, 2009 for placing it in the context of industrial networks) and Drucker that manufacturing matters, its management has become more conceptual and has grown into the product of principles and a number of practices, together seen as new approaches; lean production is a case in point. Many of these new approaches already went beyond the limits of the systems' thinking as its restrictions appeared critical during the 1980s, even though recognised later (Forrester, 1994). Hence, in the early 1990s a plea for empirical research based on quantitative analysis emerged (Flynn *et al.*, 1990; Swamidass, 1991), inspired by a social science perspective to arrive a theory; a re-iteration of this position came regularly about (Bertrand and Fransoo, 2002; Forza, 2002) and proved popular for advancing operations management science (Filippini, 1997; Rungtusanatham *et al.*, 2003). That was followed by a call for the antidote, the case study research methodology (McCutcheon and Meredith, 1993; Meredith, 1998), which picked up strongly in the beginning of the 2000s (Stuart *et al.*, 2002) in combination with action research (Coughlan and Cogghlan, 2002; Westbrook, 1995). These developments led also to taking best practice as source for new approaches (Voss *et al.*, 2002) but this type of research has strong limitations (Davies and Kochhar, 2002). Hence, this diversification of research methods (supported by Boyer's and Swink's (2008) position) resulted in either generalisations yielding limited insight (quantitative research) or solutions for specific circumstances with little attention for contingencies (as noted by Sousa and Voss, 2008). With the increasing number of publications over the past 30 years or so, the domain of manufacturing management has become entrenched in research philosophies and conceptual approaches, with no direct alternative to the aspirations of (general) systems theories as metatheory.

In the meanwhile, it has become accepted more commonly that other disciplines, such as network theories or complexity thinking (Wiendahl and Scholtissek, 1994), are seen to be much more adequate to address recent challenges for manufacturing and its management than the widespread general systems thinking approach. Moreover, shifts in perceptions about manufacturing are regularly inducing paradigmatic debates often pointing at social, resources, technological dimensions, etc. that should be included stronger and hence demanding the widening of the scope. On the other hand neither established production and manufacturing technology nor management sciences do seriously deny that their respective bodies of knowledge clearly hit limitations in applicability for an ever wider range of phenomena and loudly encourage further incorporating inter-disciplinary approaches and novel dimensions achieved by other disciplines. Prominent examples are the best practice concept of lean production being well embedded in Theory of Constraints (Jacob *et al.*, 2009) and agile manufacturing (Christopher, 2010), relying on reconfiguration principles found in nature. Consequently, considerable work in the domain of (dispersed) manufacturing networks has already been undertaken at intersections with other disciplines and fields of knowledge for providing a solid scientific base or at least for a more theoretic foundation.

However, attempts to develop more advanced theories for collaborative (manufacturing) networks, too, face deep-rooted challenges for interdisciplinary work. First, there is the extension of the validity of construct resulting from the application to aspects from the complex nature of CNs. Such extensions of validity face opposition from traditionalists whose research instruments and approaches are confined to the prevailing notions and application; examples are the non-foreseeable market movements that only immediate restructuring can cope with, but not the more common modus operandi of high-frequency adapted traditional planning. Second, disciplines already active in research work on CNs, such as social sciences and network's software agents, tend to claim all manufacturing networks as more or less trivial cases within their sciences and thus strongly marginalise outcomes of interdisciplinary research. Consequently, interdisciplinary research appears less attractive for promoting researchers (Rhoten and Parker, 2004), because its standing is lowering their benefits from the results and decreasing their motivation for further theorising (an example is Campbell's (2005) cry for help). In addition, interdisciplinary researchers face personal difficulties, as researchers rooted in more than one field may experience disciplinary critiques as the pressure on researchers in most disciplines to keep strictly engaging in "normal puzzle-solving science" is very strong (Alvesson and Sköldberg, 2000; Pickett *et al.*, 1999). Following such academic pressure to remain within traditionally established disciplines is financially and professionally rewarding and suppresses interdisciplinary outcomes. Interdisciplinary work therefore merits support, a quest that this special issue aims to support, and individual researchers should be commended for their courage to pursue such an avenue.

The practice of problem solving however shows that interdisciplinary researchers do neither see themselves as breaching disciplinary walls nor crossing disciplinary boundaries, but as conducting negotiations across different groups of disciplines (Aboelela *et al.*, 2006). Above all, they experience largely a high level of acceptance of their work by managers and other stakeholders. For CNs in manufacturing, therefore, interdisciplinary approaches have resulted frequently in quite a number of literally "unnoticed" excellently executed strategies with brilliant implementations, for example, the owner-managed German "Hidden Champions" prove (Simon, 2012; Venohr and Meyer, 2007); evidently these solutions do not attempt gaining broader interest in manufacturing and management science. Some come up accidentally and much later, as successful global capacity loading practices for global car assembly in automotive industry or flexible supply networks in local/regional small- and medium-sized enterprise contexts. Their influences on manufacturing and management science, therefore, remain limited and possible impact theory-building are far from being fully exploited.

For being able to grasp and to promote better results from interdisciplinary research in CNs and manufacturing science, and for building fecund and parsimonious theories, the roles of disciplines in science and research in general have to be clarified.

2. Disciplines, interdisciplinarity and paradigms

> Philosophy of science is about as useful to scientists as ornithology is to birds (Richard Feynman, 1918-88, Physician).

In that context, science may be named any intersubjectively verifiable examination of facts, including their systematic descriptions and – if possible – their explications (Carnap, 1966). With an identified object of interest as a starting point, any science traditionally strives for understanding and principles in line with specificities of the associated branch of knowledge, also referred to as the accounting scientific discipline within the relevant classification of sciences (Popper, 1959). Well-established scientific disciplines have considerable impact on research. The content of theory to be proven seems to strongly depend on presumptions, experiential evidence and *ad hoc* explanations that constitute scientific progress, however always tightly held together by a dominant paradigm that may as well be referred to as the identity of the accounting discipline. In this perspective, we speak of a pure discipline or of mono-disciplinarity if a certain domain is scientifically permeated with a consistent paradigmatic and theory-rich concept.

However, the environment of sciences rarely corresponds with the internal differentiation of disciplines of science to start with. Therefore, typically any progress in science is partially interdisciplinary and (applied) scientific research is indeed one of the triggers for collaboration between disciplines (Luhmann, 1990). Moreover, scientific work, notably in manufacturing and management contexts, is accompanied by reiterations to stay closer to practice (for example, co-production of knowledge as mentioned by Tranfield *et al.* (2004) and Hartley and Benington (2000)); the calls for the case study methodology and action research appearing in the first section of this paper testify to that. In this perspective, science is more and more confronted with new so-called complex problems resulting from "everyday challenges". Consequently, more holistic requirements result in especially frequent demands for adaptation of disciplines' borders and lending from other domains of knowledge. From this viewpoint, interdisciplinarity may also be interpreted as a reaction to external challenges in manufacturing, triggering efforts for establishing novel methods and concepts that promise to be more adequate to solve research items or practical problems than canonical pure disciplinary approaches appear to offer.

At this point, some clarification is needed to narrow down to the scope of interdisciplinarity as used in this special issue about CNs and in manufacturing and management research, with the intention to address the problem areas that cross the border of individual disciplines. This issue will not emphasise transdisciplinarity, where several fields of knowledge areas are providing pure disciplinary accesses and may be networked with each other by intermediate concepts (Aboelela *et al.*, 2006). Neither intends it to go deeper into multidisciplinarity, with several disciplines from different knowledge areas simply co-working within a common context (Aboelela *et al.*, 2006). Noticeable impact on disciplines and disciplines' boundaries strongly demand for "melting" together disciplines and their followers, a mechanism for which interdisciplinary research seems more promising. At the current stage of thoughts and ideas, transdisciplinarity and multidisciplinarity seem to be far less promising for CNs in manufacturing research than interdisciplinary contributions.

A permanent point of discussions is the internal differentiation of science with its consequences in terms of institutional "atomisation of the disciplines and subject areas" (Mittelstraß, 1987). From this point of view, interdisciplinarity clearly responds to progressive specialisation and knowledge fragmentation as it is widely criticised. Without interdisciplinarity, one might argue that progressing knowledge fragmentation limits innovative capabilities, usefulness of scientific knowledge or even relevance of science in general. Moreover, there are debates within this context, seriously putting into question scientific specialisations and differentiations of disciplinary knowledge as barriers to science and knowledge in total, which can only be overcome by means of interdisciplinarity. In order to leave behind such barriers to management science and manufacturing research regularly draw from external theories dependent on the problem domain or the most suitable models to be engaged with, for example, integer programming and control theory. Additionally, in manufacturing and management sciences the disciplines and categories of theories used (e.g. general systems theory, operations research) are often overlapping, since not all work falls neatly into a single school of thought or topic area. This observation may be a helpful starting point for interdisciplinary discussions, as – vice versa – many individuals' works could have been listed in more than one category; categories of theories may simply appear as temporary and heuristically useful for sorting out major approaches. In no way, they should represent any barriers for interdisciplinary work of fundamental nature. On the contrary, interdisciplinary methods are designed to answer questions differently and to study both phenomena for which we have sufficient hypotheses and phenomena about which too little is known to even formulate hypotheses within pure disciplines' frameworks.

In conclusion, interdisciplinary perspectives enable to make truly original and useful contributions to knowledge, as well as to critically review both the fields from which they draw and the domain at which they aim. Based on such conjectures, interdisciplinary researchers ally with colleagues in traditional disciplines who are also increasingly becoming open to external inputs. It is not surprising, that one of Kuhn's groundbreaking observations was that anomalies leading to the toppling of a reigning theory or paradigm almost invariably were observed by researchers whose backgrounds were in other disciplines than those in which opinion leaders in the field traditionally had been trained (Kuhn, 1962). Researchers from different disciplines generally use different methods and have different interests toward their object of study. Therefore, it is not surprising that many of the most breakthroughs in the study of management, organisations and markets have come from scholars who stood astride two or more academic disciplines.

The benefits of interdisciplinarity for manufacturing research are clearly obvious. Whether championed, vilified, tolerated, or marginalised in manufacturing and management science, interdisciplinarity has stepped in the core of its research to stay. As the departure from pure disciplinary studies, interdisciplinarity exhibits the development of theory innovation by being both an embattled site of controversy and a battle cry (Hutcheon, 1997). This is true in general, but in particular for theories for collaborative (manufacturing) networks.

3. Theory-building and disciplines

> There is no particular method guaranteeing success.
>
> Scientists do not solve problems just because they swing a methodological magic wand (Paul Feyerabend; Die Wissenschaft in einer freien Gesellschaft, 1978).

This call for interdisciplinary contributions has become prominent since increasing numbers of enterprises are faced with the huge so far unseen challenges of manufacturing efficiently in CNs and distributed structures while operating beyond the consolidated state-of-the-art. For support by theoretical insights in recent developments and up-coming concepts, the collection of contributions in this volume attempt to provide a thoroughly evaluated selection of concepts and theory approaches that ought to give considerable underpinning in response to these actual challenges. Some of these challenges may have been already outlined elsewhere; and in numerous cases, workable solutions have been predominant and of uncontested practical impact for "daily" management. Powerful theories, however, can offer additional valuable lenses, which enable managers and stakeholders to frame issues, to compensate for the unreliability of intuition and common sense, to ascertain belly feelings and to clarify many causal relationships that have impact on firms' objectives as well as resource allocation tactics. In this sense, theories have already contributed and certainly strongly will further contribute a lot to enhance modes and practice of management. For instance, the theory for bottleneck management, elsewhere referred to as the Theory of Constraints, has shed considerable light on methods for optimisation of inventory and flow of materials in factories. Also, chaos theory (a.k.a. theory of complexity) has completely revised the concepts for team structures and for strategy formation in companies. These achievements have rapidly shifted paradigms in manufacturing sciences; the resulting lean and complexity thinking is a key constituent of manufacturing science nowadays. More than for any other field, for manufacturing and management science, the dictum: "Nothing is more practical than good theory is" holds true referring to both substantial progresses in theory as well as for the credibility of managers and practitioners.

The numerous alternative definitions for the term "theory", each of them highlighting specific aspects and emphasising distinct points of view, have all in common that a theory is represented by a set of laws linked by related derivations. For example, the Popperian as well as the Carnapian Schools see theories as sets of statements: scientific theories are general theses and statements that are, as any representation, symbols and systems of characters (Popper, 1982). Similar thinking is provided by Sutton and Staw (1995), who regard "theory" as a set of logically interconnected arguments that tell a story about why certain acts, events, structures and thoughts occur. So, theories do not just ascertain practical insights, theories are considered the bases of all science and establishing powerful theories is crucial to any scientific progress, but they are also subject to discourse (Foucault, 1969). Returning to our line of reasoning, the development of appropriate theories brought considerable progress for manufacturing sciences. A case in point is the broadening of technological-driven transformations to the total organisational design of manufacturing companies by establishing the Tayloristic thinking, that could later be embedded in the General Systems Theory (von Bertalanffy, 1950, 1973). New ways of modelling, by interpreting technical transformation as inputs and outputs, allowed deeper insight into the logic of manufacturing organisations and its implications to integration of aspects, decomposition for analysis and appropriate control mechanisms. The resulting thoughts actually are indispensable constituents of all current manufacturing systems' theories.

This way of working scientifically is generally referred to as theory-building. More precisely: theory-building is considered any process aiming to produce new theory about empirical phenomena (Weick, 1995). Building of theory may occur through steps, as induction or deduction, comparative analysis or theoretical sampling within a discipline and formation of more general formal theories (Glaser and Strauss, 1967; Suddaby, 2006). Consequently, a scientist's work consists of establishing theses or systems of theses, which are systematically challenged by the researcher. Possible outcomes will be falsifications, verifications of theories or portions of it as contributions to theory-building. In his seminal work, Kuhn (1962) observed that confusion and contradiction typically are the norm during theory-building, often characterised by a plethora of categorisation schemes. One possible implication of this view may be even that theories can be scientific at one period in time and unscientific at another, depending on their progressiveness (Thagard, 1988). Using this logic, also far-reaching and apparently exotic approaches should always be further encouraged if explicative elements are seen, like during specific case studies. For approaches as holonic manufacturing or soft artefact, only much later fundamental scientific qualities came to light, in synthesis with complexity theories and life-cycle approaches. In such instance, principles of abstraction (Dekkers, 2013; Timpf, 1999) – classification, aggregation and generalisation – will support the extension of principles and solutions to becoming underpinning theories.

The domain of collaborative (manufacturing) networks seems to be momentarily in such a phase of theory-building phase. This is caused by a number of phenomena that are not explicable within established organisation theory (e.g. bullwhip effect, instability in turbulent markets). Furthermore, we observe various research approaches offering frameworks, taxonomies, guidelines, etc. in addition to a number of solution descriptions drawn from cases and projects as well as very abstract approaches built upon allegories and metaphors, for example, the footprint or the holon. For collaborative (manufacturing) networks, evidently intersections of scholarly fields and disciplines offer important opportunities to theorise in ways that challenge, reframe and redefine core issues in an emerging discipline and provide new areas for original ideas, fostering theory-building and testing. They also provide opportunities to challenge and revise accepted assumptions as well as established questions and traditions in the original fields from which theories have been drawn. For example, multi-agent systems theory totally revised logic and reasoning for decision making in CNs as well as cooperation and teamwork, including distributed problem solving, coalition formation and coordination. But with the list of examples not being exhaustive and the opportunities for grabs, we expect the number of interdisciplinary works to increase substantially over the years to come.

A more extended example for theory-building is a conjecture that has been proposed for establishing complex system sciences and theories (Kuehnle, 2012). It is set up as a collection of shells around a core of theories, enclosed by a shell of laws, principles and rules or generic elements, respectively. These shells are embraced by another shell of models that may be either newly established or frequently applied within the context. The three shells are viewed as embedded in the real world context, which is the manufacturing world, the practitioners view, the successful implementation by proving and verifying practical needs, effectiveness and adaptations. The conjecture may be seen as outcome of introducing topology to the setting of manufacturing networks, in particular the theory of manifolds. Envisioned like this, manufacturing network nodes do not represent just simple units but elements that encapsulate rich structures, able to unfold numerous attributes and properties into the attached realm of models. Manufacturing networks may then be interpreted as specific Hausdorff spaces. The topological structure of Hausdorff spaces allows separating the points representing the production network nodes and thus supports all mappings perfectly. This structure appears rich enough too, to capture a vast majority of configurations occurring in manufacturing networks. It may be accomplished by "attaching" respective models of attributes, relations and aspects as tangent spaces assigned to the manufacturing networks nodes. The manufacturing networks themselves, its attributes and its configurations appear as the quotient space of surrounding Kolmogoroff spaces (in terms of algebraic topology), which may arbitrarily "forget" or "remember" attached models allowing perfect procedures, for instance, to capture encapsulations, to fold and unfold properties, or to triggering on-off modes of self-organisation. Configurations may be modelled by indicators and attributes, and the views are expressed by "attached" tangent spaces to the nodes. In algebraic topology, the resulting set-up is referred to as a particular manifold with boundaries, where important attachments as well as all projections thereof are based upon homeomorphous mappings. Without going into further details, it can be comfortably postulated that the topological theory of manifolds has had impact on research into manufacturing networks' research on the respective research communities already. By introducing topology and the theory of manifolds, many portions of manufacturing theories (e.g. generic elements, models and principles for social agents as well as software agents' network interactions) may be reframed; other mappings permit designing novel steadily evolving network decision modes and such set-up facilitates exploiting the networks' characteristics related to cooperative games and partnership for value optimisation. This example of topology stands for quite a number of similar approaches and structures, from various backgrounds and multiple perspectives, that have been observed to stimulate research around collaborative (manufacturing) networks.

Following the principles of engineering (and other applied sciences), any framework may be accepted as theory, if it addresses most problems (consummate with the principle of fecundity), also if it is currently solving problems at the highest rate (Matheson, 1996), no matter by which notation it is articulated or presented. In this respect, we go along with Mintzberg (2005), who advocates that theory can be seen "along a continuum, from lists (categories), to typologies (comprehensive lists), to impressions of relationships among factors, to causations between and patterns among these relationships, to fully explanatory models". Management and manufacturing researchers often refer to their schemes as frameworks, taxonomies or typologies that allow identifying categories, even though this is a necessary but only first step for building theory.

More generally speaking, enforced theory-building by rigorous problem solution strategies at the intersection of disciplines and research domains has already played a vital role for producing knowledge in the area of collaboration and organisation. The original call for papers for this special issue, strongly encouraged scholars to develop less narrow, more integral views on challenges related to complex organisational phenomena, to (re)configuration modes and to manufacturing network design. Moreover, this special issue intended to ascertains that more blind spots are exposed, that powerful new lenses will not get lost undeveloped and interesting theories can reach the potential for having a full impact on both relevant disciplines for CNs and practical work (covering practitioners and projects). By better theoretical integration of practical achievements in these disciplines, key problems in manufacturing networks eventually become tractable within established research fields. As a substantial consequence, developments for networked organisations will cumulate insight and adequate frameworks more swiftly and more coherently through engaging with more widely accepted impactful models embracing strong bodies of (ready for use) knowledge.

4. Actual contributions to interdisciplinary theory for collaborative networks in this special issue

But what are practical steps to gain more theoretical insight from approaches and to integrate findings from other scientific disciplines into the domain of collaborative (manufacturing) networks? This special issue has chosen to encourage interdisciplinary contributions not only via a call for papers for an initial seminar but after peer reviews worked on hot spots or research with all participating authors (this is new for this kind of projects). What was aimed for, was a theoretical elaboration of the vast field of activities that we call interdisciplinary studies concerning collaborative (manufacturing) networks. Particularly, for manufacturing networks which may be considered as a human-governed and systematic combination by means of technological and conceptual procedures in order to transform inputs into outputs in the sense of marketable products, phenomena may be described in technological, socio-economical, social, ecological perspectives, etc. This enumeration already sketches some fundamental options to narrow down the problem domain to conventional disciplines, which is exactly not the intent of this special issue; rather, the contributions should be positioned strongly between disciplines.

Based on that notion, this special issue aims to provide authors with a platform to make contributions to the debate based on current theoretical and empirical research. Papers addressing the following questions were considered relevant:

Q1. What are elements of a general theory for collaborative (manufacturing) networks?

Q2. What are the specific characteristics of networks (issues of theory-building)?

Q3. How will interdisciplinary insight contribute to integrative theories for CNs?

Q4. How are networks to be optimised and controlled, especially in absence of a central decision-making unit?

Q5. How are decisions taken (logic and transparency) and which methods should be deployed for (re-)linking units (connectivity)?

Seven papers and a case study have been selected from work that had been handed in responding to calls for papers and after careful re-alignment in seminars and discussions with other authors as well as the guest editors in addition to the regular review process. The seven interdisciplinary contributions draw from mathematical models, complex adaptive systems, decision theory as well as "unexpected" fields of research, such as entropy, perturbations and information theory. All papers in this special issue are prominent examples for novel and innovative approaches arising from treading on interdisciplinary grounds and amalgamation of diverse theoretical constructs.

4.1 Extending supply chain management approaches beyond the traditional reach

The first set of three papers is trying to reach beyond the traditional approaches in supply chain management. In their contribution, Ivanov and Sokolov demonstrate the necessity for even strategic networks, like supply chains, that further advances can only be made by integrating very different disciplines into one concept, which they call multi-structural cyber-physical networks. Very early in their paper, this becomes already obvious when they list the many aspects needed to account for in supply chains. Because of these many aspects, the dynamics for adaptations of planning and scheduling caused by continuous interactions and the (inter)dependencies for decision making, the authors draw on a wide variety of disciplines including operations research, control theory, system dynamics and artificial intelligence; but is also relies on the use of information and communications technology (ICT) to make it successful. The continued reliability of the information systems appears in the contribution by Durowoju *et al.* when they examine how to counter disruptions. For their thoughts they draw on entropy, a topic related to chaos theory, to study perturbations as they affect the performance of the supply chain under conditions of the supply chain structure, ordering options and integration level. They conclude that each supply chain structure might be affected in different ways. The structural integrity of supply chains appears also in the third contribution by Gerschberger *et al.* as they set to determine the complexity of the supply chain structure. They do so in order to determine which parts of that structure perform more weakly under conditions of uncertainty. In their view, the proposal is building on the theories of complexity and stretching the traditional cybernetic systems' view to include the structural dynamics that also appear in the first contribution. Interestingly, they conclude that singular and consistent conceptualisations of complexity neither exist in general nor prevail with regard to a network perspective; that indicates that further works needs to be done. All three's theoretical contributions are strongly linked to capturing parameters and to formalising concepts derived from complexity theory and chaos theory.

4.2 Introducing new approaches for collaborative (manufacturing) networks

The second set of three papers offers new approaches from quite different perspectives. The fourth paper in this special issue by da Piedade Francisco *et al.* tackles network alignment by a management framework uniting strategic fit, predictive control and topological grounds. That results in a framework for a Collaborative Network Performance Management System. Remarkably, the performance measurement is based on instantiation, a principle rarely applied, but the contribution shows how this might be helpful for management of networks. The next contribution by Ma *et al.* sees collaboration in inter-firm networks as organisational change versus inertia tension field by implementing an emerging habitual domain theory that synthesises patterns for decision making and human behaviour. As point of departure they take that networks respond sluggishly to current changes and futures and are slow to respond to changes in the external environment. Most of us will perceive CNs being more agile, but does their stance raises the question that networks are subject to the same phenomena as individual organisations? And fundamentally, what do we exactly gain from networks? Part of that enquiry drives the sixth contribution by Eschenbächer and Zarvić. They show that different stages of the life-cycle of CNs are best described by different organisational theories based on the relevant traits of these networks. Hence, these three contributions only demonstrate that reliance on a single theory might poorly advance understanding of collaborative (manufacturing) networks.

4.3 Looking back and forward at theoretical advances

That point is picked up by us in the seventh contribution, an extensive outline on the role of interdisciplinarity research, intending to provide more statistical evidence about the research work around collaborative (manufacturing) networks. A structured literature review helped to gain insight in the rate of occurrence and the fields of knowledge surrounding collaborative (manufacturing) networks. A set of 202 papers has been retrieved, and by using statistics, clustering and categorisation we provide solely a clearer picture about focal points and main thrusts of research in this specific domain. However, our intention was not to praise or criticise other scholars' work as outcome of mono-disciplinary or interdisciplinary research strategies, appropriate or inapt theories or as being informed indulgently by external disciplines to the domain or not. Is it not that every single published piece of research has its unique merits and limitations. In that spirit, we have cited and interpreted research by others, but we do so exclusively to illustrate how interdisciplinary scientific progress is actually made in this strand of manufacturing science. We do believe that this contribution as a review will contribute towards consolidation and credibility for researchers as well as managers promoting Distributed Manufacturing and collaborative (manufacturing) networks; the research agenda in that contribution testifies to that.

4.4 Case study

A comprehensive case study concludes this special issue. It is a pleasure that Cheikhrouhou *et al.* have written up their experiences with the Swiss Microtech Enterprise Network, a well-known example of Collaborative Manufacturing Networks. Its set-up and evaluation, inspired by evolutionary biology and game theory, intensifies the thinking about life-cycle by drawing from complexity science and ICT as enabler. It is also a case in point for our earlier remarks that solution-oriented strategies might eventually also results in forming of theory, albeit through quite different strategies than theory-oriented research approaches.

It is this wide variety of approaches and insight that has driven not only the call for this special issue but also the actual contributions. Hence, it underlines the point that progress can only be made at the intersection of disciplines and that these steps should be considered inspriratiomal.

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As much as we discuss collaborative (manufacturing) networks, this special issue is also a result of collaboration and most of it virtually. Not only by the authors but also by the reviewers, who have very patiently and carefully examined the propositions by authors, sometimes on numerous occasions. Excellent reviews that helped all of us move forward were written by: Hamideh Afsarmanesh, Henk Akkermans, David Bennett, Luis Camarinha-Matos, W.B. Lee, Jan Olhager, Egon Müller (assisted by Sebastian Horbach), Kulwant Pawar, Klaus-Dieter Thoben and Roger Warburton. The reviewers were drawn from the Scientific Committee that included more members (Jeff Butler, Afonso Fleury, Roger J. Jiao, Bernard Katzy, Bart MacCarthy, Laure Morel, Chihiro Watanabe). Furthermore, we received support from the Business School of the University of the West of Scotland for organising the seminar. Last but not least, we should mention David Bennett, not only in his role as Editor of this journal but also his support all through (reviews and decision-making), in fact, he was more or less the third guest editor.

We sincerely hope that you will be inspired to contribute to further forming of theory and the intersection of domains of knowledge and will join us during further steps on this interdisciplinary journey.

Note

1. The term "engineering" has a somewhat ambivalent meaning. Private correspondence with Kulwant Pawar (University of Nottingham), dated 17 October 2011, highlighted this ambiguous use of the word engineering and what it covers (for that reason "product design" was used instead of "engineering" in the original publication (Riedel and Pawar, 1991)). One might also refer to it as "new product development".

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About the authors

Hermann Kühnle is Full University Professor for Factory Operations and Production Systems, at the Otto-von-Guericke-University of Magdeburg, Germany, and has been Executive Director of the Institute for Ergonomics, Manufacturing Systems and Automation since 1994. From 1994 to 2001 he also was Foundation – and Executive Director of the Fraunhofer Institute for Factory Operation and Automation IFF, Magdeburg. Since 1995, he has been the spokesperson for the research field "Advanced Production Systems in Saxony-Anhalt" and board member of several companies and venture capital groups. From 1980 to 1994 he worked for the National Fraunhofer Institute for Production Engineering and Automation (IPA), Stuttgart, on Material Flow Planning, Enterprise Planning and Organisation, Computer Integrated Manufacturing, and since 1991 as Research Director and Head of the division "Enterprise Planning and Control". During this period he initiated, built up and managed the CIM-Technology Transfer Centre for the University of Stuttgart. Since 1987, he has led a number of global, European, national and regional research programmes, as well as research consortia with leading companies, research partners and national institutes. Hermann Kühnle is the corresponding author and can be contacted at: Hermann.Kuehnle@ovgu.de

Rob Dekkers is Reader in Industrial Management at the University of the West of Scotland (since 2006), after having been a Senior Lecturer at Delft University of Technology from 1992 onwards. Before that, he worked in industry as internal consultant, production manager and senior project manager. He holds a Master's degree in Mechanical Engineering and a Doctoral degree (both from Delft University of Technology). He has (co-)authored about 100 publications on innovation and technology management, transitions in companies, manufacturing strategy, outsourcing and industrial networks. He is board member of the International Foundation for Production Research and Director of the International Association for Management of Technology, and serves on review panels and committees, e.g. the (International) Review Panels for the EPSRC. Main areas of research cover innovation and technology management, changes and transitions in companies, manufacturing strategy, outsourcing models, and industrial networks, underpinned by systems theories, science of complexity and evolutionary (biological) models.