The International Journal
ENTREPRENEURSHIP AND SUSTAINABILITY ISSUES
ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2017 Volume 4 Number 4 (June)
http://doi.org/10.9770/jesi.2017.4.4(2)

Publisher

ON SUSTAINABLE PRODUCTION NETWORKS FOR INDUSTRY 4.0*

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Received 10 February 2017; accepted 20 April 2017

Abstract. Re-industrialization enjoys a renaissance in Western economies due to the role of the industrial sector for innovation, productivity, and job creation. A very promising approach to bring back competitiveness in production seems to be the fusion of the virtual and the real world leading to smart manufacturing and logistics concepts. In Germany, the leading industrial country in the European Union this approach has been called "Industry 4.0" aiming to develop cyber-physical systems (CPS) and dynamic production networks in order to achieve flexible and open value chains in manufacturing of complex mass customization products in small series.
Currently, manufacturing companies gaining experiences in production in networks and smart logistics and develop new organisational structures and business models which better benefit from the new technologies and which adapt faster to the rapidly changing network environments. The modern manufacturing models embrace modular and fractal approaches as well as network-orientation, flexibility and responsiveness.
The paper investigates the relationship between networking, organizational development, structural frame conditions and sustainability in the context of Industry 4.0. The research is empirically validated by using data samples from a business reengineering project in an internationally operating high-tech manufacturing enterprise located in Estonia. The empiric analysis is based on semi-structured expert interviews and secondary data together with a case study approach.

Keywords: modular factory, Industry 4.0, production in network, fractals, sustainability

Reference to this paper should be made as follows: Prause, G.; Atari, S. 2017. 0n sustainable production networks for Industry 4.0, *Entrepreneurship and Sustainability Issues* 4(4): 421-431. http://doi.org/10.9770/jesi.2017.4.4(2)

JEL Classifications: L60

1. Introduction

Within the last years, many initiatives towards smart manufacturing have been started all over the world in order to re-establishing and regaining a significant industrial share in the economy (Tvaronavičienė 2014; Travkina, Tvaronavičienė 2015; Prause 2015). A promising concept is the fusion of the virtual and the real worlds of manufacturing to realise concepts for smart manufacturing and logistics by using cyber-physical systems (CPS)

* *This research was supported The research is supported by Wismar Business School, Wismar University, Germany*

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2017 Volume 4 Number 4 (June)
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together with dynamic production networks in order to achieve flexible and open value chains for complex mass customization products. The Germany interpretation of smart production, Industry 4.0, goes even beyond these objectives by additionally tackling energy and resource efficiency, increasing productivity as well as shortening innovation and time-to-market cycles (Kagermann et al. 2013). Internet–based linked machine-to-machine-interaction paves the way to networked manufacturing systems and cross-company production processes which shall enable the design and control of the entire supply chain of a product during its full life time (Bauer et al. 2014; Brettel et al. 2014).

By scanning the scene of already existing production structures which might be compatible with Industry 4.0, literature review reveals modular and fractal approaches as well as networked production concepts. Current research results on Industry 4.0 highlight that modular or fractal company concepts together with new business models for smart supply chain management might be suitable even for the integration of the SME sector (Olaniyi, Reidolf 2015; Prause 2015, 2016). Historically, Wildemann (1988) brought modular production structures into the academic discussion by stressing the intra-company view whereas Sturgeon (2002) focussed more on cross-company value chains by considering modular production networks by investigating market similar relations between designers and integrators on one side and contract manufacturers on the other side. In the case of US American contract manufacturers Lüthje at al. (2002) pointed out that these system suppliers realised scale benefits by working for different integrators at the same time. Within the concept of modular production networks the integration of different companies into a united production process are already stipulated. A cognate construction of integrating independent business units into common production processes was also coined by Warnecke (1996) in his visionary concept of a fractal enterprise for modern operations management which emphasised self-similarity, self-organization, self-optimization, goal-orientation, and dynamics as wining attributes of flexible and adaptable manufacturing organizations.

All mentioned concepts embrace intrapreneurship and entrepreneurship issues as important success factor since the underlying organizational units of a common, cross-company production process have to be able to decide and behave entrepreneurially in accordance with their self-organisation and self-optimisation objectives. Both Warnecke (1996) as well as Canavesio and Martinez (2007) stressed for manufacturing fractals the importance of a flexible relationship network made up of autonomous, but interdependent manufacturing fragments into the organizational structure which are usually linked via ICT systems. For modular or fractal production networks the importance of the entrepreneurial dimension is self-evident due to the legally independent company units in the case of modular production networks but also for the intra-company structures of modular production intrapreneurial aspects play a more important role (Wildemann 1988; Sturgeon 2002). Altogether, the modular and fractal approaches are capable to realise highly complex patterns for manufacturing that merges all the enterprise functions of an integrated organisation to improving the speed of operations and the ability to adapt quickly to changes in the environment (Shin et al. 2009).

As an important case Sydow and Möllering (2015) depicted the “Smart” car production plant of Daimler-Benz in Hambach (France) for modular structuring in the context of a production network. The Hambach plant enjoys a very small production depth of only 10% and it is organised in such a way that the supplying system partners install their delivered components or modules with their own workforce directly into the Smart car during the assembly process. Such a networked production process with modular or fractal structural components will be investigated and discussed in this paper in accordance with the already mentioned concepts we will call such structures a networked modular factory (Olaniyi, Reidolf 2015; Prause 2015).

Until now, only little research has been carried out on the sustainability of production networks in the context of Industry 4.0. The literature review of existing sustainable business and network structures together with their frame conditions in the context of Industry 4.0 indicates a research gap. For this reason, the paper addresses the

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research questions of how sustainable production networks and their frame conditions for Industry 4.0 might look like and how the intrapreneurial and entrepreneurial environment influences the success of networked production structures.
The paper is subdivided into the following parts. First part provides the theoretical background for modular and fractal production networks in the context of Industry 4.0 with an emphasis on entrepreneurship issues. Afterwards, the research methodology for the empirical part is described. Subsequently, the empirical results of the case studies and the conducted expert interviews are presented and discussed. Finally, the paper finishes with conclusions.

2. Theoretical background

Industry 4.0 seems to be one of the most promising concepts to spur re-industrialisation and industrial competitiveness in EU countries. Germany as the most important industrial European country aims with the implementation of Industry 4.0 for the development of cyber-physical systems and dynamic production networks in order to achieve flexible and open value chains coping with mass customisation products in small series up to lot size 1. But Industry 4.0 also targets on energy and resource efficiency, the shortening of innovation and time-to-market cycles, as well as on the rise of productivity. In this sense, Industry 4.0 represents nothing less than the fourth industrial revolution, comprising 3D printing, big data, Internet of Things and Internet of Services, i.e. all the ingredients needed to facilitate smart manufacturing and logistics processes (Kagermann et al. 2013).

The implementation of Industry 4.0 leads to new supply chain paradigms based on complex and intertwined manufacturing networks with changed roles of designers, physical product suppliers, clients and logistics service providers making it possible to identify and to trace single products during their entire life-cycle. As a consequence, Industry 4.0 will enable products to organise and find their own way through the production processes and the final distribution channels to the client based on open, dynamic and smart production and logistics networks (Bauer et al. 2014). Despite the fact that Industry 4.0 aims for horizontal integration, Industry 4.0–related value chains will take place in complex and intertwined manufacturing networks where the underlying supply chains can be characterized by a high degree of fragmentation (Dujin et al. 2014). This fragmentation lowers the entry barriers for SMEs and opens up new R&D strategies in multinational value chains and the creation of new business models (Belussi, Sedita 2010; Prause 2015).

The organisational aspects of fragmented value and supply chains have been discussed intensively in literature. Wildemann (1988) studied modular structures by concentrating more on intra-company production by emphasising the client focus. Sturgeon (2002) discussed modular production networks and the relationships between the corporate entities consisting of designers, integrators and contract manufacturers. Lüthje at al. (2002) analysed the case study of an US American contract manufacturers and highlighted that these system suppliers were able to realise scale benefits by cooperating with different integrators parallel. Another, but close concept was coined by Warnecke (1996) with his operations management model of a fractal enterprise which emphasised self-similarity, self-organization, self-optimization, goal-orientation, and dynamics as wining attributes of flexible and adaptable manufacturing organizations. Olaniyi and Reidolf (2015) pointed out the compatibility of fractal structures with Industry 4.0 by highlighting the ability for self-organization, self-optimization, goal-orientation, and dynamics as success factors. But all concepts dedicate large attention to disposition, decision making and innovation.

Pinchot (1984) introduced the term intrapreneurship and defined intrapreneurs as "Those who take hands-on responsibility for creating innovation of any kind, within a business". Most scholars have investigated research questions how managers and employees could be inspired to behave entrepreneurially, to create innovations, to obtain profit and growth through these innovations and to foster the creation of new businesses within existing

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organizational framework (Burgelman, 1983; Zahra 1993; Brazeal 1993; Bowman 1999; Sathe 2003; Rezk et al. 2016).

In this understanding intrapreneurship refers to initiatives of employees in organizations to undertake something new, i.e. the intrapreneur uses innovation and creativity to transform an idea into a profitable venture within an organizational environment so that an intrapreneur can be considered as an “inside entrepreneur” who follows the objectives of his organization.

In his modern concept of a lean startup Eric Ries (2011) investigates companies that are both more capital efficient and that leverage human creativity more effectively. His lean entrepreneurship approach is inspired by the lean manufacturing concept of Toyota and aims to reduce wasted time on creating elaborate business plans and instead to more rely on testing visions continuously, to adapt and adjust “validated learning,” rapid scientific experimentation, as well as using practices to shorten product development cycles and measure actual progress (Womack, Jones 1996). Thus, the lean start-up approach enables a company to shift directions with agility and to alter plans step by step. In the interpretation of Eisenmann et al. (2012) lean start-ups represent companies that follow a hypothesis-driven approach to evaluating entrepreneurial opportunity, i.e. the entrepreneur in a lean start-up translates his vision into falsifiable business model hypotheses, and then tests the hypotheses in series of "minimum viable products" which represent the smallest set of features needed to validate empirically a concept. On the base of the test feedback the entrepreneur has then to decide if he wants to stick to their business model by modifying some business model elements or to abandon the start-up. By doing so the lean start-up approach evaluates the entrepreneurial opportunities in an evolutionary way by mitigating cognitive biases that lead to bad decisions.

Until now literature review reveals that the lean entrepreneurial concept has not been adapted to intrapreneurship. Besides that, the lean start-up approach embraces characteristics of agility which is atypical for lean manufacturing concepts since the evolution from lean manufacturing to the younger agile and responsive production concepts was mainly initiated by a changing manufacturing focus towards flexibility and responsive supply chains in order to be able to cope with the needs of mass-customization (Maskell 1994; Womack, Jones 1996; Christopher 2000). But the realisation of agility requires dynamic capabilities together with an organisational slack which comes along with a higher level of entrepreneurial and intrapreneurial freedom for the involved employees and teams. (Cyert, March 1963, Teece et al. 1997; Brown et al. 2000; Sydow, Möllering 2015). Consequently, the lean entrepreneurship or intrapreneurship approach fits well with agile and responsive manufacturing concepts despite the conflicts between lean manufacturing and agile or responsive production in the context of supply chain models.

Beyond that, current research point out the importance of intrapreneurial and entrepreneurial capacity in the context of Industry 4.0 due to self-organisation and self-optimisation needs of the underlying organizational units for their business success in a dynamic and open production network environment (Olaniyi and Reidolf, 2015; Prause, 2015, 2016; Atari, Prause, 2017). The fragmentation of Industry 4.0 – value chains facilitate the integration of SMEs into fractal and modular manufacturing organisations since they offer solutions for the agile work of SMEs as virtual entities in the network in cooperation with much bigger and grounded enterprises since those organisations are designed to combine the logistic attributes of manufacturing with the strategic configuration of agile capabilities (Panetto, Molina 2008; Raye 2012). Especially, the fractals concept gives room for the integration of information and manufacturing structures which facilitates to cooperate and to optimise the resource allocation (Panetto, Molina 2008; Shin et al. 2009). Such networked approaches require less supervision which amplifies the freedom for intrapreneurial and entrepreneurial activities for the employees in the fractals and modules and consequently the control is less complicated and more easily understood (Ryu et al. 2003).

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3. Methodology and case study

Primarily, the research used a qualitative approach to the problem solving. Nevertheless, the research employed practices of both qualitative and quantitative research, i.e. both forms of data were collected at the same time during 2016 and then integrated the information in the interpretation of the overall results. The research methodology was based on a mixed exploratory approach by using qualitative case study methods together with semi-structured expert interviews as well as quantitative analysis of internal business process data. Additionally, other field methods such as observations were combined quantitative assessments. The empiric measures concern the Estonian production plant of an international operating high-tech company which headquarter is based in Scandinavia. The research was conducted during in the packaging department in Tallinn during a business process reengineering project in the company which was initiated by the management of an Estonian production plant in order to improve performance.

The Estonian production plant started in the 1990ies when Estonia became independent from Soviet Union. Most of the products manufactured in Tallinn plant are delivering to the target market's customers located in Eastern Europe and Central Asia. A couple of years ago the company faced economic and political recession which had a negative impact and it causes the rapid decrease in production. Consequently, the company started downsizing plans accompanied by the introduction of lean concepts in order to cut costs and to avoid losses. The business reengineering activities also touched the packaging department of the Estonian where the first decision of the management at the beginning of the costs cutting activities in the packaging department was dedicated to downsize the packaging unit by reducing the space and man power for completing the packaging cycle and the inventory.

After the economic situation recovered the management of the Estonian production plant had to react on increasing incoming orders despite the fact that the full implementation of the lean management concept has been only partly realised comprising a Kanban system, just-in-time logistics and Kaizen events but unfortunately no lean culture with a corresponding mind set of the workers has been developed at this time. Nevertheless, since the handling of the incoming orders needed more space that was not available space in the vicinity of the factory the management decided to outsource parts of the production processes including the packaging activities. Since the Scandinavian headquarters of the Estonian production company decided to re-establish only those business units in Estonia which are needed for the delivery of products to the customers, important business units were no longer available in the Estonian packaging department including the packaging design part which existed only once as a central packaging design unit in the headquarters.

Consequently, three new partner companies for logistics and the completion of the packaging cycle were contracted for Estonia in order to form a new packaging department realising a networked modular enterprise for consisting of four different company units, namely the packaging department of the Estonian production plant itself, the subunit of the global logistics service provider and the three Scandinavian packaging materials suppliers which are integrated into the supply chain in a form of cooperative engineering partners for packaging providing more than 90% of the complete packaging solutions. The global logistics service provider is fully independent of the Scandinavian company and has its headquarters in Germany whereas the three packaging materials suppliers also have their headquarters in Scandinavia and during later the expert interviews it turned out that the two packaging material suppliers are linked together with the production company by cross-ownerships via a Scandinavian financial holding.
The packaging process can be described so that the unpacked final products come from the manufacturing site into the residual packaging line of the plant where they are prepacked in form of a single shrink pallet. For the finalisation of the packaging they are transferred with the help of an inbound logistic supplier to the packaging production area of a subcontractor not far away from the production site where the packaging process is

completed. In this construction all autonomous business units of the four involved companies are acting together in an operations network which is linked by the operations process of packaging and where the operations within the integrated process are realised by own company employees comparable to the modular company concept of the "Smart" car production in Hambach (Sydow, Möllering 2015).

Unlike the situation in Hambach the packaging process blueprints an organisational form of a strongly structured with standardised and uniform tasks so that the networked modular packaging can be considered as an assembly process without variants. Nevertheless, all included business units in the packaging process are realising their own contributions with their own workers so that from outside the construction looks like a virtual company and by considering the inner structure together with the discussed literature the networked packaging company can be characterised as being fractal or modular. By comparing the underling business structure to concepts of Industry 4.0 it turns out that no flexible network of autonomous operations units exists and also the cyber-physical manufacturing systems instead of workers is missing. Thus, the full dynamics of an Industry 4.0 – production network is not entirely realised in the case study because the products are not finding their own way through the network and the production process is still strongly prescribed. Nevertheless, the modular packaging company might be considered as a pre-Industry 4.0 production structure and solutions concerning sustainability and the performance shall be discussed in the sequel.

The implementation of the modular networked packaging enterprise delivered a running stable solution and the construction had the advantage that it avoided a duplication of business units. But at the same time another problem appeared all process modifications in the Estonian plant needed to be negotiated and approved in the central design unit in the headquarters which made changes, adaptations and innovations in packaging department and as well in the networked packaging enterprise complicated and time consuming. Thus, a packaging process change had to be transferred after approval by the headquarters to all packaging partners companies and the concerning business processes had to be redesigned and implemented in cooperation with the partner companies in order to implement the new packaging solutions in accordance with to the company's guidelines. This procedure was very slow and limited significantly the intrapreneurial freedom in the networked packaging enterprise. In addition to that a lack of packaging designers in the Estonian production plant made all changes in the packaging department to a big challenge and lowered the innovation level. Furthermore it turned out that the business structures of the four involved independent fractals in the Estonian packaging unit were not fully compatible due to different organisational standards so that the performance of the virtual packaging unit was weak.

Consequently, the management of the Estonian production plant initiated a business reengineering project in order to increase efficiency and performance of the complete the production cycle including the packaging department. The business reengineering project focussed on technical improvements by neglecting intrapreneurial and cultural aspects as well as the implementation of compatible organisational standards. The objective for the packaging department was to reduce the packaging material cost and to create a new design for the full product packaging. The targets for the cost reductions in the packaging department were savings up to 80% which turned out to be a very ambitious objective. In order to reach these targets the Estonian management integrated external research units into the business reengineering project and the results of the research and simulation showed cost savings potential for the packaging department up to 60% due to the use of new packaging materials and designs which was not possible to be implemented immediately so that the reengineering process was on hold for a longer period. Additionally, the cost savings of the packaging processes in the modular packaging enterprise required new process design and new workflows in all involved fractals so that the implementation of the new solutions to the production line needed more time than expected. Another important reason for the delay and the implementation problems was related to the lack of authority in decision making processes, the dependency from the headquarters and ongoing cultural mismatches within the networked modular enterprise caused problems until

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now to unlock the efficiency gains for the modular packaging enterprise, i.e. due to underdeveloped intrapreneurial freedom together with a non-consistent business environment within the networked modular company was responsible for delays in the implementation of efficiency gains.

In addition to the fact that the production company as well as its principal partners have their headquarters in Scandinavia, the expert interviews revealed conflicts appearing from the financial linkage by cross-ownerships of the three packaging material suppliers and the production company in the same Scandinavian holding controlled by family investors. Regardless that Morck andYeung (2003) stress the important role that family firms play in free economies, it is important to analyse how the parts of a family business are linked together. In the case study the main policies of the owners was to force the cooperation between firms of the family group with the consequence that competition was abolished which reduced significantly the competitive advantages of the common holding. In addition to that, the forced cooperation in the financial holding cancelled the freedom of choice and with it the competition among a variety of suppliers which was exactly the case in the principal production company when the sourcing of packaging material was restricted to only the three packaging providers.

From the expert interviews the authors also gained the insight that the main company and its suppliers did neither have the same vision nor the idea which kind of a common management system or an organisational standard to implement. Thus the experts stated that the non-existing organisational standards generated frictional costs at the interfaces between the different parts of the virtual company. Furthermore, the experts added that the information exchange together with an integrated IT system was always missing so that one crucial requirement for successful and sustainable fractal or modular structures was not realised. Consequently, it was nearly even impossible to acquire management relevant information in order to decide or behave entrepreneurial. One high profile engineers made clear in an interview that access to relevant data is problematic so that decisions related to efficiency and business performance. Thus the controllability of the business process was not safeguarded by the existing information infrastructure so an adequate entrepreneurial and intrapreneurial decision making was possible which impacted negatively the efficiency and performance of the virtual packaging company.

4. Discussions

Self-organization, self-optimization, goal-orientation and dynamics are success factors for flexible and adaptable manufacturing organizations, fractal enterprises as well as for Industry 4.0 (Warnecke 1996; Olaniyi, Reidolf 2015). Since self-organisation and self-optimisation requires entrepreneurial and intrapreneurial freedom to be able to control and improve the business processes of the involved units. The forced cooperation policy of the financial holding company together with required approvals from the Scandinavian headquarters for business process changes in Estonia reduced the entrepreneurial freedom of the Estonian subsidiary and its departments significantly with the consequence that it was impossible for the Estonian production company to improve efficiency by looking for new reliable suppliers with more competitive prices. These results stress again the need for entrepreneurial freedom together with self-organisation and self-optimisation properties for the creation of efficient networks of productions which are based on autonomous units like in the context of Industry 4.0 (Warnecke 1996; Sturgeon 2002; Kagermann et al. 2013). A possible mitigation strategy for fixing these inefficiencies might be a “lean intrapreneurship” approach in the sense of Ries (2011) which could safeguard the right entrepreneurial freedom in the fractals of the networked modular company. But the case also showed that in an operations network with autonomous components the organisational standards and cultures must be compatible in order to ensure seamless organisational interfaces.

This is of special interest for operations networks in Industry 4.0 because of the use of cyber-physical systems and self-guided product flow through the network the interfaces of the different network components have to be

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unified to avoid frictions which result in inefficiencies, longer throughput time or additional costs. Even in the case study of the packaging department where compared to Industry 4.0 only a minimal organisational slack was necessary to construct and operate the networked modular company the absence of entrepreneurial or intrapreneurial freedom caused in the packaging department a deadlock in the field of innovation due to constraints and blockings for the implementation of improvements. In the case of Industry 4.0 the availability of organisational slack is even more crucial to enable the development of “dynamic capabilities”, to facilitate flexibility and responsiveness of the supply chain and open resources for self-organisation and self-optimisation.
The empiric results of the case study also revealed that the Estonian production plant never develop a mature organisational culture so that the employees were missing a common organisational mind-set which caused organisational inefficiencies within the production plant and which it also made complicated to communicate and cooperate efficiently at the cross-company interfaces within the virtual packaging company and which caused high transaction costs due to organisational frictions. By following Liker and Rother (2011) it can be stated that continues improvement is something that the personnel is not assured automatically how to achieve, so it needs entrepreneurial mind set and skills as well as the appropriate frame conditions, which was not safeguarded in the investigated situation. Consequently, various expensive reengineering projects were initiated in the packaging unit but they all failed to a big extent.

Finally the case study pointed out a lack of access to process data making it impossible to measure, control and improve the business processes. Thus, the quality of communication and the information exchange in networked environments was not appropriate to secure efficiency, performance and the achievement of the unit goals of the underlying operations network. In this sense the information exchange is the glue that links the parts and that integrate the parts to an operations network. The timely information for fractals is crucial to make decisions and respond to issues as they come up (Strauss, Hummel 1995). But information is also necessary to back and support the intrapreneurial decisions in the fractals to safeguard costs, time, quality and allocation of resources as well as collaboration with other fractals (Strauss, Hummel 1995). All these frame conditions were not realised in the modular packaging company so that it no surprise that the performance gains were not able to unlock until now. Changes in the frame conditions represent necessary preconditions to improve the efficiency in the production network. But the frame conditions for Industry 4.0 have to be further investigated and developed especially in the context of organisational slack, dynamic capabilities and openness.

5. Conclusions

Industry 4.0 aims to develop cyber-physical systems (CPS) and dynamic production networks in order to achieve flexible and open value chains in manufacturing of complex mass customization products in small series. Currently, manufacturing companies gain experiences in production in networks, smart logistics and the development of new organisational structures and business models. Modular and fractal approaches can help to benefit from network-orientation, flexibility and responsiveness.

The case study of an internationally operating high-tech manufacturing enterprise located in Estonia highlights the relationship between networking, organizational development, structural frame conditions and sustainability in the context of Industry 4.0. The empiric analysis of the packaging department which is organised in form of a networked modular production unit reveals that beside technical aspects the performance of a networked construction suffered heavily under the underdeveloped organisational environment. By transferring the results in the context of Industry 4.0 it turned out that a successful networked approach require intrapreneurial freedom in the sense of Ries’ “lean entrepreneurship” approach, a suitable local decision power and organisational standards as well as an adequate information supply. In the context of Industry 4.0 these frame conditions have to be further developed towards agile and responsive supply chain structures, “organisational slack” and dynamic capabilities.

Since in the case study these frame conditions were not fulfilled, it was impossible to unlock significant efficiency gains in the planned range.

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Aknowledgements

This research is supported by Wismar Business School, Wismar University, Germany

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