Proceedings of the Hamburg International Conference of Logistics (HICL) – 23

Julia Wagner, Henning Kontny

Use Case of Self-Organizing Adaptive Supply Chain

Published in: Digitalization in Supply Chain Management and Logistics
Wolfgang Kersten, Thorsten Blecker and Christian M. Ringle (Eds.)
ISBN 9783745043280, Oktober 2017, epubli

Use Case of Self-Organizing Adaptive Supply Chain

Julia Wagner[1], Henning Kontny [1]

1 – HAW Hamburg

The main drivers for the development and implementation of self-organizing adaptive operation processes are the increase of flexibility while lowering costs in times of growing consumer demands, shaping the supply chain into "the source of enterprises core competence". This paper is based on the "Guidelines for conducting and reporting case study research in software engineering" and it demonstrates the design of the self-organizing adaptive supply chain through an integration of processes and systems. As a result, the automated near real-time data flow enables shorter order-lead-time with a high accuracy of information. Although the study includes the architecture for the self-organizing adaptive supply chain, it cannot be completely standardized due to individual processes and IT-systems within different companies. Academics and practitioners may find it useful to identify appropriate scenarios while looking for the ways to digitize their supply chains.

Keywords: Self-Organizing Systems; Adaptive Supply Chain; Digitalization; Use Case

1 Introduction

Today's consumers require the products they have ordered to be delivered faster and faster, and innovative products should be offered within shorter and shorter time-to-market cycles. What industry is able to achieve today, will soon be insufficient (Bauernhansl, ten Hompel and Vogel-Heuser, 2014). This expands the role of Supply Chains (SC) to the "source of competitive advantages"(Ponte et al., 2017), considering that they include all the material and information flows as well as processes from sourcing (purchasing), internal activities (manufacturing, assembly, storage etc.) to product shipping. In order to stay competitive and to be able to satisfy growing customer demands, companies are striving toward the application of new IT systems. There are some industries which even completely depend on the IT in supply chains such as the meat industry, where transparency through the shared data between different suppliers and buyers could help to prevent scandals involving meat products (Kassahun, Hartog and Tekinerdogan, 2016). In recent studies the supply chain is viewed as one of the most important criteria for commercial success (Wellbrock, 2015; Yuvaraj and Sangeetha, 2016), which also should be adaptable to changing demands in the interest of potential growth (Bogaschewsky et al., 2016; Fuller et al., 2013) and as a consequence is even called „moving authority" (Plattform Industrie 4.0, 2016).

Nevertheless, small and medium-sized enterprises (SMEs) have rather immature IT-systems along supply chains, despite the fact that they generate around 50% of GDP of developed countries and are responsible for 60% of employment (Kumari et al., 2015). Although SMEs usually have an ERP and production systems, many decisions such as production planning, purchasing volumes for raw materials etc. are usually taken with help of numerous Excel sheets or Access Databases also known as Shadow IT (Rentrop and Zimmermann, 2012; Jones et al., 2004). Other scientists (O'Leary, 2008) underline that around 90% of supply chains are fragmented and not digitalized end-to-end. As a result, the entire process of order fulfillment remains very slow and is vulnerable to mistakes.

At the same time, the vision of the Internet of Things (IoT) or also known as Industry 4.0 is arising, targeting the interconnection of physical objects such as product or a machine with the enterprise systems, allowing companies to collect real-time data as well as to automate simple decisions based on historical data. "The IoT allows things' and 'objects', such as RFID, sensors, actuators, mobile phones, which, through unique addressing schemes, (…) interact with each other and cooperate with their neighboring 'smart' components, to reach common goals"(Dittrich et al., 2008). This leads to a decentralized execution of business processes, thereby increasing process efficiency and transparency.

Research studies underline the need to provide a reference architecture integrating IoT services (Dar et al., 2015) in order to enable the spread of new technologies. Other authors(Gunasekaran et al., 2016; Duan and Xiong, 2015) add that visibility as one of the most important organizational capabilities can "revolutionize existing supply chains". However, as the McKinsey Survey of over 300 industrial companies from the USA, Japan and Germany shows, most enterprises have difficulties in defining a convertible strategy for the implementation of the Industry 4.0 to gain competitive advantages, despite their high interest in doing so. "Digitalization is important, but we are not prepared enough" (McKinsey Digital, 2016).

For these reasons, the main objective of this paper is to describe a process of the development of a Self-Organizing Adaptive Supply Chain based on the case study for a greater understanding of such a complex project.

2 Theoretical Background

2.1 Self-Organizing Adaptive Logistics

Although adaptable processes which allow balanced execution of operations under unstable conditions are in focus of many research articles, the design of such remains little known (Bogaschewsky and Müller, 2016).

The concepts of Self-Organization/Autonomy are used in this case study in the context of an automated data analysis, with an independent reaction to changes, including self-configuration and self-optimization by systems, up to the level of an entire self-organization. This is an indispensable component of the Industry 4.0 or Internet of Things. Examples for self-organizing are the generation of automated procurement orders, control of supplies or consumption of materials etc. (Agiplan GmbH, Fraunhofer IML and Zenit GmbH, 2015). Self-Organizing Adaptive Logistics: "focuses on the entire inter- and intra-logistics structure" in order to increase flexibility and reaction time using efficient data analysis to make better decisions or counteract possible disturbances of processes. It is closely linked to the logic of Order-Controlled Production(Plattform Industrie 4.0, 2016) although it encloses the integration of all operational processes and material movements (End-to-End Supply Chain).

Autonomous logistic components which are capable to communicate among each other will become “Smart Objects”, which are intelligently connected with each other and are able to independently optimize themselves as an adaptive, co-operating group, whose further development will lead to a decentralized self-organized logistics system with complete fusion between the physical and the virtual world (Voß, 2015).Although adaptable processes which allow balanced execution of operations under unstable conditions are in focus of many research articles, the design of such remains little known(Kersten et al., 2015). On the other hand, IBM, Siemens, Cisco and other firms (O’Leary, 2008) underline the need for autonomic systems, arguing that human intervention requires higher costs and longer periods of time.

2.2 Related Work

The estimation of the efficiency of decision-making by human participants in comparison to IT systems has occupied scientists for a long time. Measurable results for such comparison were provided at the XXI International Conference on Industrial Engineering and Operations Management 2015, where scholars (Costas et al., 2017) presented results of an IT system (Agent-Based Modelling and Simulation) playing the well-known Beer Distribution Game. BDG was presented by Sterman (1989) at the MIT Sloan School of Management and is widely used to observe the Bullwhip Effect known from Forrester (1968), which represents one of the basic concepts of Supply Chain Management. Human players were not able to deal with a high-load of information and uncertainties and as a result, they were outperformed by the IT system in every single parameter, which managed to keep a low inventory level ($3,641 IT vs. $21,662 Human decision) in combination with low lost sales ($4 vs. $652).

3 Methods and Approach

3.1 Design of Use Case

The use case was designed according to "Guidelines for conducting and reporting case study research in software engineering"(Runeson and Höst, 2009), which underlines the importance of case studies for investigation of complex issues, especially involving humans in interaction with technology. Case study methodology is closely related to action research (Dittrich et al., 2008; Gorschek et al., 2006), which is focused on change processes such as software process improvement or technology transfer studies. Whereas the analysis of the effects of a change is classified as a case study (Runeson and Höst, 2009). The case study allows to "investigate a contemporary phenomenon within its real-life context"(Shahin, 2015) and represents a comprehensive analysis of several of cases (Waterman, 2014). This paper represents the cumulative results from several projects:

1. Coffee manufacturer, over 2.000 employees, project "End-to-End digitization of Supply Chain".
2. LED (light-emitting diode) producing company, over 2.000 employees, focus on digitization of Demand and Supply Chain processes.
3. Manufacturer of air filters and signaling technologies, over 500 employees, project "Cyber Assembly" focusing on the digitization of assembly, production, warehousing and purchasing.

The above-mentioned projects present the following similarities:

- Focus on the digitization of decision processes and automated data flow.
- Aiming at fast and precise data exchange across at least four independent departments.
- New and/or changes in customer orders trigger the calculation of production, warehouse etc. volumes.

The setup of the use case includes the subsequent steps, which according to Perry et al. (Perry, Sim and Easterbrook, 2004) separate the case study from an experience report:

1. Clearly defined research question

2. Systematic data collection and analysis in order to answer the research question

3.2 Research Question and Data Collection

Due to the high pressure of consumer expectations, it is crucial to understand the requirements of the market and to be able to adapt to them instantly, which leads us to the research question:

What are the main requirements and design principles for the Self-Organizing Adaptive Supply Chain?

As the proper design of the case study needed systematic data collection, it was carried out on the basis of face-to-face interviews as well as through workshops with managers and scholars. The process mapping and development of the target process acquired in each case over ten single interviews (see Table 1) with experts from departments of production, logistics, controlling and planning on national and international levels. The results were documented as event-driven process chains (EPC) on a very detailed level as well as two flow charts on a higher level, each of the process ”as is” and target process. Both EPCs and flow charts were reviewed and if required supplemented during three two-day workshops with the responsible managers. Subsequently, the developed architecture of a current status of processes and systems was confirmed as appropriate by responsible managers. At this stage of the projects, the data was analyzed mainly on a qualitative level in form of process steps, timeline and information flow.

Table 1: Interviews for process mapping.

Company	Timeline	Interviewer	Interviews
Coffee manufacturer	10/2011 – 12/2011	First Author, external Consultant	14
LED producer	11/2013 – 04/2014	First Author	23
Manufacturer of air filters	09/2016 – 12/2016	Both Authors	12

In pursuance of a development of a robust target process, the method of the "operation recording" (Herrmannsdoerfer and Koegel, 2010; Lippe and Van Oosterom, 1992; Langer et al., 2013) was adopted – which is a documentation of the processes within the modelling environment, while the processes are actually being performed.Subsequently, the developed architecture of a current status of processes and systems was confirmed as appropriate by company executives.

3.3 Process Mapping

In order to document and present the results of data collection in a structured and comprehensible way the concept of Enterprise Architecture was chosen, which is according to Ross (2006), includes business processes and IT infrastructure in order to fulfill long-term operation needs as well as to plan the projects. ISO/IEC/IEEE defines an architecture "as composed of: (a)the fundamental organization of a system embodied in its components; (b) their relationships to each other, and to the environment; and (c) the principles guiding its design and evolution."(ISO/IEC 42010: 2007-Systems and software engineering–Recommended practice for architectural description of software-intensive systems, 2007). Other scholars (Tekinerdogan, 2014) add that a software architecture represents the structure of the systems on a high-level and is relevant for the stakeholder communication, design decisions including the planning of implementation project and allocation of tasks.

In this way, the study supports the IT experts with the business knowledge that is necessary for the supply chain digitalization. Although IT units primary knowledge is technical, it is essential that IT managers understand the potential challenges for the SC digitalization from a business perspective (Xue, 2014), which leads to more effective communication between IT and operation departments and thus better results for the development projects.

4 Architecting the Self-Organizing Adaptive Supply Chain

4.1 Case Description

Company X is a typical medium-sized enterprise with a business model of purchasing raw materials from outside and executing operations in-house (Kumari et al., 2015), then selling products to diverse customers (as shown in Material Flow in figure 1). For example, a coffee company would buy green coffee beans, roast them (equal to the "pre-production" process step), blend the beans and pack them in diverse types of packaging in units of 1000g, 500g or 250g (equal to "production planning 2" step as shown in figure 1). As with many SMEs, company X had no in-house consulting or a strategic IT department. Subsequently, the business grew over the years, but supporting systems stayed at the same level as of their implementation over ten years ago. In contemplation of significant increase of customer demand other production locations with additional warehousing were acquired. Despite additional production capacity, the order-lead-time (time between the customer order and delivery of the order) was not shortened. In times, where Amazon and other "Big Players" offer very short delivery times, order-lead-time became one of the critical factors of success in the consumer market. For these reasons, the main aim of the project was to provide the IT solution for an adaptive supply chain with the following targets:

- End-to-end digitalization of data along the supply chain
- Shorter order-lead-time (from over 2 weeks to 1 week)
- Lower level of inventory (reducing the average 4-6 week safety stock to 2 weeks)

4.2 Adaptive Supply Chain Architecture

The approach of the visualizing of existing business processes and systems was based on principles presented by Panunzio (Panunzio and Vardanega, 2014), who underlines that software architecture:

- Should stay at a high-level, "does not pollute"
- And at the same time "meaningfully represents those entities and their semantics".

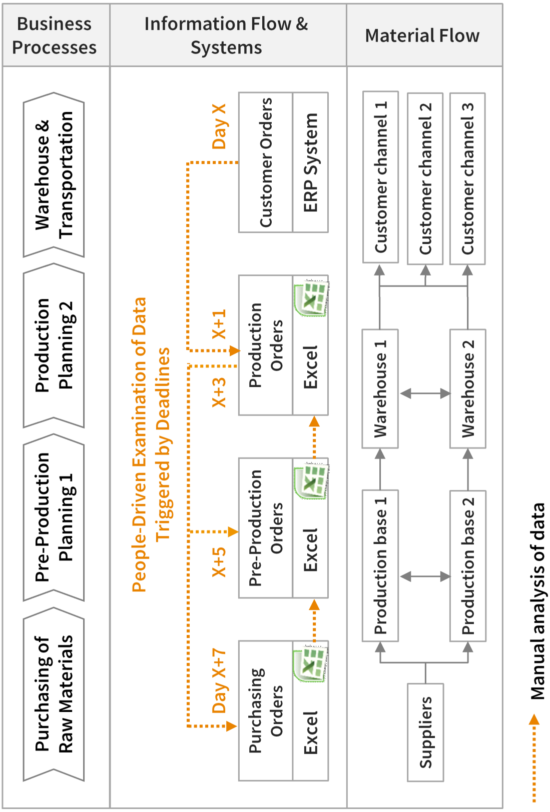

Figure 1: Operational Processes ”As Is”

For these reasons the Enterprise Architecture was structured into the three most important levels:

— High-level business processes (which also match the organizational structure of departments)

— Information flow including systems used for decision-making

— Material flow from suppliers to customers.

Based on numerous face-to-face interviews the first version of the Enterprise Architecture “As Is” was created (the processes outside the supply chain such as finance, marketing etc. were left out of scope). It showed that although the ERP system contains all the information about articles such as master data, bill of material, the information about customers and suppliers; the relevant decisions on volume of orders, evaluation of supplier performance (at purchasing departments) and production planning (in production departments) were still met based on diverse reports exported into Excel. This way of working caused a very slow reaction by the company to the changes in customer orders (as shown in figure 1). Additionally, the data in different departments had different levels of accuracy in comparison to the real-time data. For example, the production orders for Monday in the production system were based on data from Thursday of the last week, whereas pre-production operations were lagging even further behind. The purchasing department, which purchases the raw materials, takes that decision not based on actual customer orders (they will still be taken into a consideration), but on the information from production, thus creating additional waiting time. All these facts lead to the conclusion, that the more participants, who change the data and need 1-3 days for the alignment with others, a process has, the longer the order-lead-time will be.

The next step was the planning and execution of workshops with managers of respective departments who are responsible for business processes. As a result, all participants agreed that the current IT systems do not provide the required level of support to the processes and should be improved. The material flow was left out-of-scope for the target architecture because the increase in its complexity over recent years due to new production bases and warehouse as well as an additional customer channel had no significant impact on the structure of the processes or systems. Considering that the decision-making process for the production, pre-production and purchasing of goods took over 50% of the order-lead-time, it was agreed to automate those calculation processes without substantial changes in material flow.

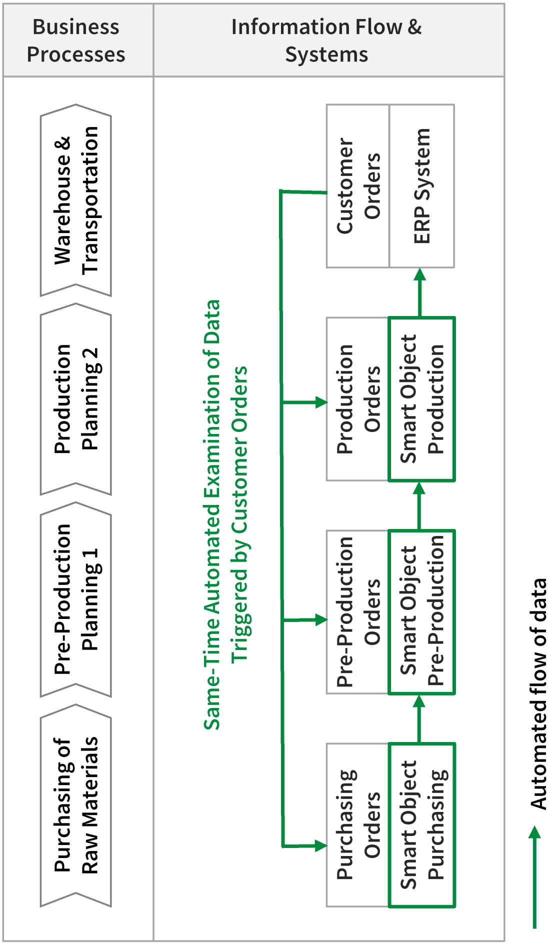

Figure 2: Adaptive Supply Chain

Which led to the target process, as shown in figure 2. In target process "Adaptive Supply Chain with Autonomous Information Flow" the customer orders are viewed as a trigger for the new calculation of production volume, which leads to the calculation of the pre-production volume, which as a result can cause new purchasing orders. Thus all departments will receive the data at the same time and the entire Supply Chain will be able to adapt itself to new customer orders within a short period of time.

The target architecture of systems and processes is not only intended to implement a new customized IT solution but also to change the information flow and as a result the entire method of working. It was agreed to define the target process based on the concept of Self-Organization/Autonomy with interconnected "Smart Objects" for autonomous data processing in each process group, such as Purchasing, Pre-Production, Production, as well as Warehouse & Transport as defined by Bischoff and ten Hompel (Agiplan GmbH, Fraunhofer IML and Zenit GmbH, 2015). In this way, they can independently analyze and share the data as well as take decisions on production and purchasing volumes. As a consequence, the people who work, for example, in purchasing department will be supported with data in near real-time mode, and employees in different departments will have same data at the same time.

4.3 Quality Requirements for Master Data

The self-organizing system can only exist if the master data is correct and the connection between single products, parts etc. is explicitly defined. For example, from the perspective of production planning of LED bulbs the end product of so-called twin-blister (2 products in 1 packaging) is the same product as "normal" bulb of the same type and can be produced in the same batch. For the packaging, warehouse and customer/consumer these are unequal products. If the twin-blisters should be sold from display instead of from regular shelves, they will be seen as different product type by the marketing department, even if they seem to be the same product for the customers and consumers. Consequently, the End-to-End communication strongly depends upon the ability to dissolve and reassemble the data generated by the needs of each process group or "Smart Object". Thus for the accurate information exchange throughout numerous departments master data should fulfill following requirements:

- All product variants such as differences in packaging for the co-equal product, products in marketing campaigns, packaging with different languages etc. should be differentiated in a system.
- All product components should be clearly identified in a system, regardless of their size.
- All bills of material and packing lists should be kept up-to-date.
- Explicit assignment of data – one product number should not be used for more than one type of product.

4.4 Implementation

Although the target architecture at a high-level was developed in one piece, the development and deployment of the software were separated into work packages according to the principles of the continuous deployment (Shahin, 2015):

- Small and independent deployment units.
- Considering operational aspects.
- Testability inside the architecture.

The operational focus in the architecture allowed the separation of the software solution into manageable independent units, starting with the operation next to the customer orders and moving toward the purchasing orders. Such an approach freed up the focusing on one task at a time, making the whole process transparent and manageable.

For example, the first task was to automate the decision in the production planning “should we produce the ordered volume or should we deliver the goods from the available stock?” At first sight, it is a very complex decision which involves many factors such as information about customers, seasonality for some products due to Christmas and other typical marketing promotions. There are many theories, on how to make an accurate decision as well as demonstrations of wrong decisions i.e. well-known Beer Distribution Game from Sterman (Sterman, 1989), which represents a tendency to accumulate unnecessary inventories called the Bullwhip effect (Forrester, 1968). Nevertheless, even under such complex circumstances, it is possible to automate the decision process and even improve the overall performance (Costas et al., 2017) using statistics and algorithms for the calculation of the safety stock.

Subsequently, the target process for the production planning was tested for one product group simultaneously to the “as is process”, which led to further improvements on the master data (s. Chapter 4.4). As a result, the production planning was performed ongoing in the background, starting the new calculation as soon as a new customer order which was higher than average planned volume entered the ERP system. In comparison to the old process, where the production planning was performed once per week one week upfront to the start of production, it drastically increased the reaction time of the whole supply chain and shortened the order-lead-time.

Other working packages were designed based on same logic as an example, making the whole process robust and transparent, saving time for the data analysis and decision-making.

In the first project the validation of the software was based on the Requirements Specifications which represented the target Architecture of IT-Systems on a detailed level. The requirements were documented and divided into mandatory and optional functions of the software. The validation of the second project solution was result-based: the automated flow of data improved the forecast accuracy by 13% five months in a row, which led to more precise purchasing volumes and as a consequence to lower level of stocks of finished goods and spare parts. The third project will be validated in 2017 based on a simulation of the business processes in a real-time mode simultaneously to the processes ”As Is”.

4.5 Risks and Benefits

Pressure to deliver high-quality value and deploy faster (Shahin, 2015) may cause a situation where sub-optimal solutions will be chosen over originally required systems, which would cause “architectural technical debt”, which is similar to a financial debt and has to be repaid in the long term (Vogel-Heuser et al., 2015). In our case, it would mean the risk of introducing a new solution which is incomplete, so that both old and new way of working would exist at the same time, causing high costs, low efficiency of a new system and most importantly, mistakes in relevant business decisions such as purchasing volume, production and the delivery of goods.

Despite the risks and high expenses of the implementation, the Adaptive Self-Organizing Supply Chain can produce multiple benefits, which can be divided into operational and strategic (Xue, 2014).

- Operational: lowering logistics costs, lowering operational costs, improving inventory control, increasing inventory turnover.
- Strategic: establishing a competitive advantage, improving customer relationships, improving supplier relationships.

In our use case, all the companies benefited from a shortening of order-lead-time by at least two weeks, which lead to lower level of inventory, not only for finished goods but also for spare parts and consequently, the costs for storage and handling. Thus, the benefits unquestionably outweighed the risks, which reduced the resistance towards changes within the company and accelerate the process of gaining acceptance.

5 Discussion

5.1 Contribution to Research and Practice

This study contributes to the topics of Self-Organizing Systems and Adaptive Supply Chains by providing a clear structured use case. The combination of real-time online data and increasing computer processing power has an immense impact on architecting new systems since it allows autonomous data collection and processing (Mortenson, Doherty and Robinson, 2015). In our use case, the automated data flow had a massive impact on the order-lead-time and accuracy of information.

However, as exemplified in the analysis of 52 research papers undertaken by Dikert (Dikert, Paasivaara and Lassenius, 2016) and a survey of almost 4,000 respondents executed by VersionOne Inc.(VersionOne Inc, 2016), the following barriers must be taken into consideration on the way to the implementation of projects:

- General organizational resistance. As stated in the ”Manifesto for Agile Software Development”, which came out in 2001 in USA (Fowler, Martin, Highsmith, Jim and Cockburn, Alistair, 2017), it is important that business people work together with the software development throughout the whole project in order to enforce the communication while lowering the resistance.

- Pre-existing rigid framework. Since the new software solutions will be implemented on a basis or with the co-existence with older software models, it is crucial to understand the evolution of predecessor models (Langer et al., 2013). Clearly defined requirements for the software allow for the technical implementation as well as the contractual relationship between the software providers and the process owners, which allow mitigating of the relevant project risks (Panunzio and Vardanega, 2014).

5.2 Limitations

The impact of the new system could be quantified only in terms of order-lead-time and accuracy of information. The impact on logistics and operational costs could not be precisely measured, due to complexity in the real-world environment:

- Change of sales volume at the end of various periods of time. Sales volume has a massive impact on costs per product since logistics costs are highly impacted by rent costs of the warehouse, costs of warehouse operator etc. Therefore it is hard to evaluate the exact impact of the new software implementation if the sales and product range were changed; even if the costs at the end of the reporting period were lower than before the rollout of the software.
- Other projects and marketing campaigns. Since the software project was not the only project in companies, it is impossible to separate the impact of one project on a company's performance (in all three cases the companies operate globally). A good example is the almost 40% reduction of so-called penalty costs (costs to B2B customers for not achieving service level agreements) after the roll-out of software. Although the software doubtless supported this achievement, it is still difficult to measure the exact level of influence, due to simultaneous application of a new system of financial reward for the employees by the management.

In order to investigate the potential for costs reduction due to the implementation of Self-Organizing Adaptive Supply Chain, the Business Innovation Lab at University of Applied Sciences in Hamburg will launch a research project, in which the influence of single parameters can be changed and evaluated on demand in controlled environments, based on the simulation of events.

A further limitation results in the difficulty of standardization of an IT-Solution for the development and implementation of a Self-Organizing Adaptive Supply Chain since every company has a specific business model and already has one or more customized IT-System with which new software will have interfaces. For this reason, it is important to have a methodological approach for evaluating the potentials and problems in each single case.

Due to the high complexity of software projects, the study is limited to the area of supply chain processes. However, the proposed approach can still be used for the development of an architecture for Self-Organizing Systems within other business areas such as marketing, R&D and sales.

6 Summary

The main task of the Supply Chain is to steer the processes throughout the different departments both inside and outside the company. This can only increase the performance of the entire company if the data collected by different participants and systems are interlinked with each other instead of the digitalization of the activities of only one department (Yuvaraj and Sangeetha, 2016; Coltman, Devinney and Midgley, 2011; Xue, Ray and Sambamurthy, 2013). It is also important to keep in mind, that an autonomous information flow does not mean 100% computer-based decisions. There is still some low percentage of errors or situations, where human interaction is required. However, even the partial implementation of the automated information flow makes the whole supply chain more robust and flexible to the changes in customer demand. The implementation of the self-organizing adaptive supply chain as a new and innovative business strategy supports companies by the extension of transparency of organization-wide processes. This in turn, enables data-based decision-making processes, which impact the market share and even help us to discover new strategic capabilities (Hazen et al., 2016). When supply chain activities achieve better results through the automation of decisions, it generates cost savings and improves the economic benefit for the company, shaping the supply chain into “the source of enterprises core competence” (Vogel-Heuser et al., 2015).

References

Agiplan GmbH and Fraunhofer IML and Zenit GmbH (2015). *Erschliessen der Potentiale der Anwendung von "Industrie 4.0" im Mittelstand*.

Bauernhansl, T., M. ten Hompel, and B. Vogel-Heuser, eds. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik*. de. DOI: 10.1007/978-3-658-04682-8. Wiesbaden: Springer Fachmedien Wiesbaden.

Bogaschewsky, R. and H. Müller (2016). *Industrie 4.0: Wie verändern sich die IT-Systeme im Einkauf und SCM?*

Coltman, T., T. M. Devinney, and D. F. Midgley (2011). "Customer relationship management and firm performance". In: *Journal of Information Technology* 26.3, pp. 205–219.

Costas, J., B. Ponte, D. de la Fuente, J. Lozano, and J. Parreño (2017). "Agents Playing the Beer Distribution Game: Solving the Dilemma Through the Drum-Buffer-Rope Methodology". In: *Engineering Systems and Networks*. Springer, pp. 337–345.

Dar, K., A. Taherkordi, H. Baraki, F. Eliassen, and K. Geihs (2015). "A resource oriented integration architecture for the Internet of Things: A business process perspective". en. In: *Pervasive and Mobile Computing* 20, pp. 145–159.

Dikert, K., M. Paasivaara, and C. Lassenius (2016). "Challenges and success factors for large-scale agile transformations: A systematic literature review". en. In: *Journal of Systems and Software* 119, pp. 87–108.

Dittrich, Y., K. Rönkkö, J. Eriksson, C. Hansson, and O. Lindeberg (2008). "Cooperative method development: Combining qualitative empirical research with method, technique and process improvement". en. In: *Empirical Software Engineering* 13.3, pp. 231–260.

Forrester, J. W. (1968). "Industrial dynamics—after the first decade". In: *Management Science* 14.7, pp. 398–415.

Gorschek, T., P. Garre, S. Larsson, and C. Wohlin (2006). "A model for technology transfer in practice". In: *IEEE software* 23.6, pp. 88–95.

Gunasekaran, A., M. Kumar Tiwari, R. Dubey, and S. Fosso Wamba (2016). "Big data and predictive analytics applications in supply chain management". en. In: *Computers & Industrial Engineering* 101, pp. 525–527.

Hazen, B. T., J. B. Skipper, J. D. Ezell, and C. A. Boone (2016). "Big data and predictive analytics for supply chain sustainability: A theory-driven research agenda". en. In: *Computers & Industrial Engineering* 101, pp. 592–598.

Herrmannsdoerfer, M. and M. Koegel (2010). "Towards a generic operation recorder for model evolution". In: *Proceedings of the 1st International Workshop on Model Comparison in Practice*. ACM, pp. 76–81.

Jones, D., S. Behrens, K. Jamieson, and E. Tansley (2004). "The rise and fall of a shadow system: Lessons for enterprise system implementation". In: *ACIS 2004 Proceedings*, p. 96.

Kassahun, A., R. Hartog, and B. Tekinerdogan (2016). "Realizing chain-wide transparency in meat supply chains based on global standards and a reference architecture". en. In: *Computers and Electronics in Agriculture* 123, pp. 275–291.

Kersten, W., T. Blecker, C. M. Ringle, and epubli GmbH, eds. (2015). *Sustainability in logistics and supply chain management: new designs and strategies*. eng. 1st ed. Proceedings of the Hamburg International Conference of Logistics (HICL) 21. OCLC: 933219309. Berlin: epubli GmbH.

Kumari, S., A. Singh, N. Mishra, and J. A. Garza-Reyes (2015). “A multi-agent architecture for outsourcing SMEs manufacturing supply chain”. en. In: *Robotics and Computer-Integrated Manufacturing* 36, pp. 36–44.
Langer, P., M. Wimmer, P. Brosch, M. Herrmannsdörfer, M. Seidl, K. Wieland, and G. Kappel (2013). “A posteriori operation detection in evolving software models”. en. In: *Journal of Systems and Software* 86.2, pp. 551–566.
Lippe, E. and N. Van Oosterom (1992). “Operation-based merging”. In: *ACM SIGSOFT Software Engineering Notes*. Vol. 17. ACM, pp. 78–87.
McKinsey Digital (2016). *Industry 4.0 after the initial hype. Where manufacturers are finding value and how they can best capture it*.
Mortenson, M. J., N. F. Doherty, and S. Robinson (2015). “Operational research from Taylorism to Terabytes: A research agenda for the analytics age”. en. In: *European Journal of Operational Research* 241.3, pp. 583–595.
O’Leary, D. E. (2008). “Supporting decisions in real-time enterprises: autonomic supply chain systems”. en. In: *Information Systems and e-Business Management* 6.3, pp. 239–255.
Panunzio, M. and T. Vardanega (2014). “A component-based process with separation of concerns for the development of embedded real-time software systems”. en. In: *Journal of Systems and Software* 96, pp. 105–121.
Perry, D. E., S. E. Sim, and S. M. Easterbrook (2004). “Case studies for software engineers”. In: *Software Engineering, 2004. ICSE 2004. Proceedings. 26th International Conference on*. IEEE, pp. 736–738.
Plattform Industrie 4.0 (2016). *Aspects of the research roadmap*.
Ponte, B., E. Sierra, D. de la Fuente, and J. Lozano (2017). “Exploring the interaction of inventory policies across the supply chain: An agent-based approach”. en. In: *Computers & Operations Research* 78, pp. 335–348.
Rentrop, C. and S. Zimmermann (2012). “Shadow IT”. In: *Management and Control of Unofficial IT. ICDS*, pp. 98–102.
Runeson, P. and M. Höst (2009). “Guidelines for conducting and reporting case study research in software engineering”. en. In: *Empirical Software Engineering* 14.2, pp. 131–164.
Shahin, M. (2015). “Architecting for DevOps and Continuous Deployment”. en. In: ACM Press, pp. 147–148.
Sterman, J. (1989). *Modelling Managerial Behavior: Misperceptions of Feedback in a Dynamic Decision Making Experiment.*
VersionOne Inc (2016). *10th Annual State of Agile Report.*
Vogel-Heuser, B., A. Fay, I. Schaefer, and M. Tichy (2015). “Evolution of software in automated production systems: Challenges and research directions”. en. In: *Journal of Systems and Software* 110, pp. 54–84.
Voß, P. H., ed. (2015). *Logistik – eine Industrie, die (sich) bewegt*. de. DOI: 10.1007/978-3-658-10609-6. Wiesbaden: Springer Fachmedien Wiesbaden.
Waterman, M. G. (2014). “Reconciling agility and architecture: a theory of agile architecture”. In:
Wellbrock, W. (2015). *Innovative Supply-Chain-Management-Konzepte*. de. DOI: 10.1007/978-3-658-09181-1. Wiesbaden: Springer Fachmedien Wiesbaden.
Xue, L. (2014). “Governance–knowledge fit and strategic risk taking in supply chain digitization”. en. In: *Decision Support Systems* 62, pp. 54–65.
Xue, L., G. Ray, and V. Sambamurthy (2013). “The impact of supply-side electronic integration on customer service performance”. en. In: *Journal of Operations Management* 31.6, pp. 363–375.