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Procedia CIRP 72 (2018) 898–903

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51st CIRP Conference on Manufacturing Systems

Transparency in Global Production Networks: Improving Disruption Management by Increased Information Exchange

S. Treber[a,*], G. Lanza[a]

[a]wbk Institute of Production Science, Karlsruhe Institute of Technology (KIT), Kaiserstraße 12, 76131 Karlsruhe, Germany

* Corresponding author. Tel.: + 49 721 608 44297; fax: +49 721 608 45005. *E-mail address:* Stefan.Treber@kit.edu

Abstract

Modern companies operate in global production networks. The operational performance of production networks is hampered by disrupting events. Digitalization and the horizontal interlinkage of production networks may increase information exchange and lead to more transparency. It is propagated as being an enabler for a faster identification and reaction to disruptions. This paper presents a metamodeling approach that maps disruptions as systematic parameter variations and analyzes their impact on the performance of production networks under different level of information exchange. The method aims for the determination of cause-effect relationships and contributes to the determination of the appropriate level of information exchange in production networks.

Keywords: Global production networks; transparency; disruption; information exchange; metamodeling

1. Introduction

In recent decades, globalization has led to profound structural changes in economy [1]. Global competitors, shorter product life cycles, an increasing product variety and a volatile demand are causing a strong increase in competition [2]. As a result, companies of any size have built up global production networks [3,4]. Global production networks offer many advantages such as production of customized and regionally differentiated products close to the market, exploitation of low production and procurement costs as well as access to local knowledge, skills and resources [3,5]. However, growing dependencies on partners, the emergence of changes [6] and quality management [7] pose difficulties.

At operational planning level, the handling of disruptions, in particular, presents challenges. Disruptions are triggered by events such as product quality issues, machine breakdowns, bankruptcy of suppliers and problems in order processing [8–10]. These events have a negative impact on the operational performance of production networks [10]. Due to the increasing interconnection of the partners of production networks, many possibilities for the occurrence of disruptions do exist and the source of disruption is usually not within the scope of action of one's own company [11]. In the same time, the vulnerability of production networks has increased as efforts such as lean- and just-in-time-principles have eliminated time, capacity and storage buffers [12]. Last but not least, channels to communicate and to react to disruptions are long and non-transparent in global supply and sales markets [11].

A new enabler for dealing with disruptions is the ongoing digitalization. It is based on key technologies for linking machines and people by sensors [13], for identifying, tagging and tracking objects [14] and for evaluating large amounts of data [15]. These technologies open up new possibilities for the

* Corresponding author. Tel.: +49-721-608-44297; fax: +49-721-608-45005.
E-mail address: stefan.treber@kit.edu

2212-8271 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.
10.1016/j.procir.2018.03.009

increased generation, exchange and interpretation of data. Referring to industry surveys, the horizontal interlinkage of partners thus made possible may improve the control of production networks. The main advantages lie in better decisions [16], limitation of the negative impact of the disturbing events [17] as well as optimization of the reliability of processes and supply in general [18]. However, monetary- and time-related efforts prevent companies from increasing the transparency of their production networks [17]. Companies also see risks such as the loss of control over data and the disclosure of sensitive information [18]. For these reasons, companies need to be supported in improving their disruption management by increased information exchange.

2. Principles

2.1. Production networks and their vulnerability to disruptions

Global production networks serve for cross-company production. They use specific resources and competencies of the partners involved. The production takes place at globally distributed locations whereby the partners are linked to each other via exchange relationships in the form of material and information flows. [19–21]

The tasks of operating global production networks include the actual execution of processes such as production-, warehouse- and transport-management [22]. Referring to [23], these tasks can be influenced by deviations. These differences from planned values are particularly disturbing and result in order changes, quality deviations as well as changes to the final product. [23] Disruptions are caused by events. The consequence of a disruption is an undesirable effect. It expresses itself as a lack of performance. Production systems that have high and stable performance despite the occurrence of disruptions are said to be robust. Robustness can be measured using performance measurement systems. [10] In particular, the detailing of different temporal phases in the identification and reaction to disruptions is of importance for disruption management in production networks. [24] differentiates different phases whereby the perception of the disruption, the recognition of the need for a reaction and decision on an adequate measure is of interest for this paper.

2.2. Role of information exchange

Information is being exchanged between partners when executing any of the tasks of planning and operating global production networks. In this case, information refers to data that has a semantic meaning as well as a context and is being exchanged between a sender and a recipient. The recipient changes his awareness of the situation by receiving the information. [25] In global production networks, the exchange of information takes place in the form of bidirectional and continuous flows [23]. If the exchanged information is new or hitherto secret, an increase of information transparency takes place [26].

Information that is exchanged by partners of the production networks can be distinguished by their type and characteristics. Transaction-, status-, and master-information are different types of information. Transaction information is communicated when an event happens. Status information describes states such as for example the condition of a machine. Master data, the third type of information, represents the properties of objects such as products or machines. Important characteristics of information are their actuality, accuracy, quantity and confidentiality. The actuality describes the timing of the shared information. Accuracy makes a statement about the precision of the shared information. By contrast, quantity refers to the amount of and the access to the information. Confidentiality indicates to what extent the information is worth being protected against disclosure to unauthorized persons. [27]

Increased information exchange in global production networks has a positive impact on performance. Referring to literature, information exchange may improve operational efficiency, increase responsiveness and enable new forms of cooperation [28,27]. The bullwhip effect is probably the most well-known example of a lack of information exchange. It refers to the effect of an increased variance of customer demand contrary to the material flow of value chains due to lack of information exchange. [29]

2.3. Simulation and metamodeling of production networks

Simulation refers to modeling a system with dynamic processes in order to obtain insights that are transferable to reality [30]. Different simulation modeling principles do exist. In discrete event simulation, systems are modeled as a series of discrete processes. Agent-based simulation depicts the behavior of agents where an agent is a system that is situated in an environment. The agent perceives the environment and acts according to its own agenda over time. Continuous simulation is another simulation modeling principle. It serves for the time-independent simulation of a systems behavior including its complexity and dynamics. [31,32] In order to simulate processes in production networks, event-discrete simulation is appropriate. In combination with an agent-based simulation, the individual behavior of the partners in the production network can be simulated as disruptions occur.

Targeted investigations of the behavior of simulation models can take place through systematic parameter or structural variations [30]. Such experiments are suitable to determine the interactions between disruptions, information exchange and production network performance. However, the corresponding experimental plans become very large with increasing degree of detail of the simulation models. Furthermore, the complexity rises with increasing number of parameter combinations to be examined on the side of disruptions and information exchange. In this case, the application of metamodels is appropriate (see Fig. 1). Metamodels, also known as surrogate models, approximate simulation models with short computation time and sufficient accuracy. Based on mathematical methods, they provide answer sizes for any combination of parameters to be examined. Mathematical methods for metamodeling are for example radial basis functions, kriging or neural networks. The use of metamodels is not state of the art. Challenges lie in the choice of the appropriate mathematical method and the generation of the training data for feeding the metamodel using the simulation model. The adaptation of the mathematical model to the simulation model results as well as the assessment of the metamodel by means of quality criteria are also challenging. [33–35]

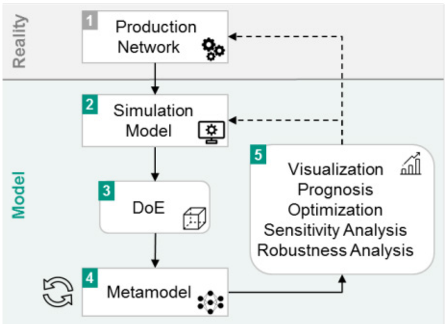

Figure 1: Approach for metamodeling global production networks

3. State of the Art

Transparency increase of global production networks has been acknowledged to be a suitable method to improve disruption management. Recent research provides scientific contributions to investigate the role of collaboration and integration on supply chain resilience and to improve supply chain performance through improved visibility and information sharing [28,36–40]. However, the variety of these approaches only focuses on disturbances which result in order changes. They neglect disturbances resulting in quality deviations as well as changes to the final product. In addition, this research stream is mainly based on qualitative methods deploying interviewing and case studies. These methods are not suitable to quantify interactions and cause-effect relationships between disturbances, information exchange and the performance of production networks. Other approaches investigate and optimize the performance of production systems and supply chains by applying metamodeling methods [41–43]. However, these approaches disregard the potential positive impact of information exchange and they do also not assist in determining the measures that should be implemented to increase information exchange. Besides, other approaches exist that focus either on KPI-systems for measuring transparency [27] or on increasing transparency by individual technologies such as radio-frequency identification (RFID) [44,45]. These approaches have a limited scope of consideration but will be taken up as a preliminary work.

4. Objective

The objective of this paper is to present a method for investigating the interactions between the performance of operational processes in global production networks, disturbing events and the level of information exchange between the network partners. The research leading questions are illustrated by Fig. 2. The subject of the paper is production networks for series production as they are common in the automotive supplier industry. Only the impact of an increase of information exchange on the production network performance is investigated. The structure of the networks as well as the production systems of the network partners are considered to be fix. Disruptions will be considered, that result in order changes, quality deviations or changes to the final product. The objective is to improve the performance of disruption management by changing the information being exchanged by the production network partners. The type of information to be exchanged as well as the characteristics of the information will be varied.

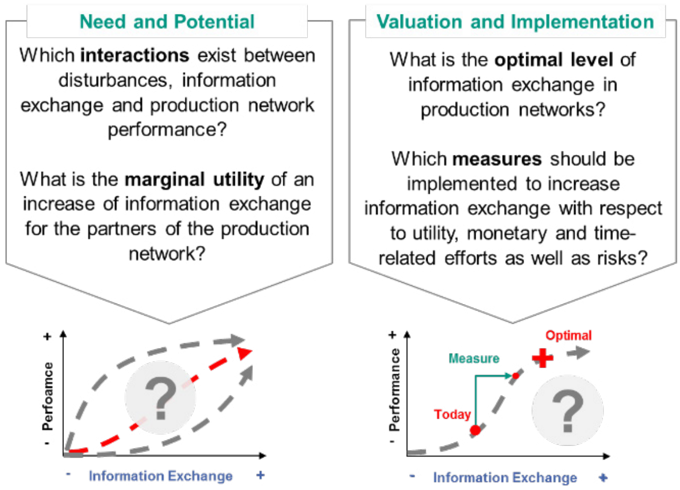

Figure 2: Research leading questions

5. Method for transparency increase of global production networks

The method for investigating the interactions between the performance of operational processes, disturbing events and the level of information exchange in global production networks consists of three steps.

5.1. Characterization of production systems, performance, disruption management and information exchange

The first step of the method involves tasks that are carried out once and independently of the specific industry application. The work serves as preparation for the implementation of parameterizable modules for event-discrete and agent-based simulation of production networks.

First, an ideal scheme for the characterization of production systems in production networks will be set up. On the basis of a literature research the essential features of processing order changes, quality deviations and changes to the final product are collected. These features will be sorted to individual characteristics as well as associated characteristic values. Care is taken to ensure that the characteristics and values have conceptual relevance, can be combined logically independent of each other, and apply to the typical production systems of the automotive supply industry (see Fig. 3).

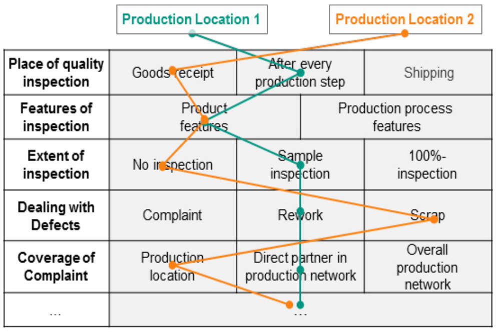

Figure 3: Characteristics and characteristic values of processing quality deviations

As a next step, a KPI system is set up. First, individual KPIs for measuring the performance of processing order changes, quality deviations and changes to the final product are defined. The KPIs are aligned to the classic targets of time, quality and costs. An example of a time-related indicator for evaluating the performance of order changes is the orders lead time. Following, the individual performance indicators are interlinked to a KPI system. For this purpose, the KPIs are aggregated to a hierarchy level with the three levels: production system, production location and production network. They are also weighted in favor of the dominant network partner. In addition, a robustness indicator is defined for each performance indicator under consideration.

In order to determine the effects of the occurrence of disruptions in the production networks, possible disruptions in the production location-, company- and global environment are subsequently collected. The occurrence of an unmanageably large number of disruptions is conceivable. Therefore, disruptions are characterized according to their intensity, probability and duration of occurrence. In addition, the disruptions are assigned to specific receptors in the production network. These are network objects such as suppliers, machines or even a product where disruptions occur and their effects unfold. The aim of the receptor assignment is to no longer have to consider a multitude of different disruptions in the later simulation model but to limit the consideration to a manageable number of disruption effects.

Finally, business processes for managing order changes, quality deviations and changes to the final product are defined. Depending on the ideal scheme for the characterization of production systems, different business process variants will be defined. The business processes are modelled in form of event-driven process chains, as they can easily be transformed into an agent-based simulation model at a later time. The focus of business process modelling is in particular the definition of different process variants depending on the information available to the partners of production networks. The determination of process steps with mutual exchange of information as well as the characterization of the exchanged information is important (see Fig. 4). The characterization of the information takes place on the basis of information types (transaction-, status- and master-information) and properties (actuality, accuracy, quantity and confidentiality).

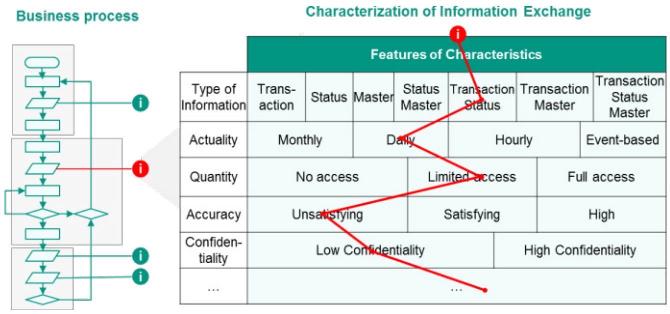

Figure 4: Characterization of business processes and information exchange

5.2. Simulation and metamodeling of the interactions

The subsequent tasks of the second step of the method are carried out partly independently and partly depending on the specific industry application.

First, application-independent, event-discrete and agent-based simulation modules are implemented referring to the ideal characterization of production systems, the KPI system, disruptions, business processes and exchange of information. AnyLogic is used as simulation software. The possibility of reusing and linking simulation modules enables a fast set-up and parameterization of large simulation models on a case-by-case basis depending on specific industry applications. The simulation modules must be verified and validated by various techniques before they are used.

All tasks after completing the verification and validation of the simulation modules must be carried out on a case-by-case basis. This applies primarily to the determination of the interactions between disruptions and information exchange. For a concrete simulation model of a production network, a statistical test plan is set up (DoE). When executing this plan, the simulation model is reparametrized according to different combinations of disruptions and information exchange. For each combination, a corresponding simulation run is performed. Depending on the design of the test plan, several combinations may be examined simultaneously (full factorial versus fractional factorial design). Depending on the number of influencing factors to be investigated and the desired accuracy of the results, the experimental plans vary in size. Figure 5 provides an overview of all variable influencing factors that may be investigated.

In the further course of the work, a metamodel is trained with the simulation run results of the test plan. The metamodel approximates the simulation model. It provides a continuous functional model of causal relationships with greater meaning. Its development represents a successive approach, since alternative mathematical methods of metamodeling are available. They must be assessed for their quality and the most appropriate method must be selected. In particular, a statistical over- and underfitting by the training data set of the experimental design should be avoided. The interpretation of the metamodel takes place via a response surface. It shows the behavior of the performance as a function of the influencing factors and can be displayed graphically in the case of two influencing factors (see Figure 5). A complete graphical interpretation of the metamodel is impractical due to the large number of influencing factors considered and the existence of high-dimensional and massive result data sets. For this reason, the significant relationships are determined via feature selection. These statistical significant influencing factors are of particular importance for the next step of the method.

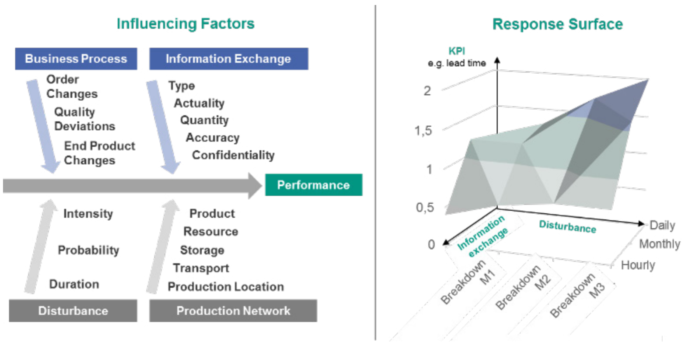

Figure 5: Design of Experiment (DoE) and interpretation of metamodel result

5.3. Measures for increase of information exchange

Within the third step of the method, a target picture for the exchange of information in the production network is formulated. The target picture picks up on those interactions between disruptions and information exchange that have been identified as being significant on the basis of the metamodeling. For the remaining combinations, an increase in information exchange does not suggest any significant performance improvement. As part of the formulation of the target picture, the types and characteristics of the information to be exchanged in the future are defined for each individual process step of processing order changes, quality deviations and changes to the final product. The determination takes place with respect to the scheme for the characterization of information exchange (see Fig. 4).

Following, case-specific real world measures to increase the information exchange will be identified and planned out based on literature research and expert workshops. The measures can be both technical measures (e.g. condition monitoring, tracking, smart labeling) and organizational measures (e.g. introduction of an online platform for order handling) and pursue the goal of putting the target picture into reality. A valuation of the measures in terms of their monetary as well as their effort for temporal implementation follows. Finally, it will be assessed to which extent the increase in information exchange leads to an unwanted disclosure of sensitive information.

The actual comparison of measures relies on the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method. TOPSIS allows a relative comparison of measures. By doing so, neither the performance increase measured on the benefit side nor the monetary and temporal effort for implementation on the cost side have to be aggregated to a uniform comparative measure. The relative comparison takes place by determining a virtual best-case and a virtual worst-case alternative as a first step. As a second step, the efficiency, in other words the benefit-cost ratio, of each measure relative to the best- and worst-case alternative is determined. The most efficiently assessed measures offer the highest utility of increasing information exchange. These measures should therefore be implemented in the production network. Up to which efficiency value an actual implementation of the measures takes place, depends on the will to invest and the risk affinity of the partners of the production network in the specific application case.

6. Application to an industrial use case

The presented methodology is currently applied to a real world production network in the automotive supply industry for the production of brush holders. The production network consists of four production sites. Production tasks such as punching the power feed, overmolding the feed, equipping electronic components and final assembly are carried out. Information is only exchanged bilaterally within the production network. Disruptions are identified too late and not well communicated within the network. The production processes, key performance indicators and business processes were recorded and implemented in the simulation model. The implementation of the metamodel as well as the identification of measures to increase the information exchange are part of current research.

7. Conclusion

This paper introduces a three-stepped method for increasing transparency in global production networks. First, production systems and information exchange in global production networks are characterized. A KPI-system as well as a receptor model for performance measurement and characterization of disruptions are set up. Second, a simulation and metamodeling based approach is used to determine the interactions between disruptions, information exchange and performance of production networks. Referring to the significant interactions, real-world measures for increasing information exchange are evolved and assessed for their efficiency in the last step.

This paper is based on current research performed at wbk Institute of Production Science. Future work focuses on the finalization of the implementation of the simulation- and metamodel. Also the investigation of the measures to increase information exchange as well as the application of the methodology in a comprehensive industrial case study are in progress.

Acknowledgements

This research has been supported by the research project LA2351/35-1 “Kennzahlensystem zur Robustheitssteigerung verketteter Produktionssysteme” of the German Research Foundation. This is gratefully acknowledged.

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