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MANAGING GLOBAL PRODUCTION NETWORKS: INTEGRATING PERFORMANCE MEASUREMENT INTO AGENT BASED SIMULATION TO SUPPORT STRATEGIC DECISION MAKING

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Abstract

In a globalized economy, companies face increasing challenges in improving their production networks. The management of these networks is a complex task, where individual target systems and a multi-criterial view including factors of sustainability have to be taken into account. To meet these requirements, a performance measurement system for production networks will be presented. This system is embedded into an agent based, discrete event and unitized simulation model to evaluate the performance of different configurations of production networks.

Keywords: production networks, decision making, agent based simulation, performance measurement

1. INTRODUCTION

In the last decades, companies internationalized their production because of three main aspects: a close-to-market production of customer-individualized products, to gain competitive advantages due to a reduction of production- and sourcing-costs and to gain access to local resources [1]. As a result, global production networks with multifarious supply- and performance-correlations between intra-corporate production sites, external partners and suppliers have emerged [2]. The challenge for companies is to manage their production network effectively and efficiently. Therefore, the individual production sites are often assigned to a strategic role (e.g. low-cost factory, high-tech factory) with the target to empower them to a higher performance in the interest of the company [3]. Due to this, the production sites get more autonomous and define their individual optimization tasks in the scope of their individual target system.

This paper describes a methodology that enables companies to perform a production-site-overlapping performance-assessment of the production network. The individual target systems, which are a result of the different strategic roles and their heterogeneity in the collaboration between the individual partners, are in the scope of this methodology. The implementation of this methodology into an agent-based, discrete event and unitized simulation environment allows a fast assessment of different network- and location-configurations, the identification of potentials for optimization and a dynamic evaluation of concrete improvement measures (e.g. the configuration of internal supply chains, measures to improve the quality of products and processes) before their implementation. Furthermore, the target dimension sustainability will be considered in the developed methodology.

2. MANAGEMENT OF GLOBAL PRODUCTION NETWORKS

The following section gives a short overview on the state-of-the-art regarding the relevant topics in context of the developed methodology. Global production and role-concepts of production sites in global production networks and the resulting individual target systems, performance measurement systems of production networks considering aspects of sustainability, multi-criterial decision making and agent-based simulation are the main topics that are presented in this section.

Because of the described development of global production networks, their management gets increasingly important for the success of a company [4]. For the design of production networks, questions regarding the geographical allocation of the production sites respectively the technology, resource- and capacity-allocation and the strategic role respectively the targets of the location, are important [2, 5]. These issues are always part of a target system, which hierarchically combines the sub-targets of individual sectors to higher targets. These targets are derived of the companies' strategy, which is depending on the strategic role of a factory.

Therefore, Wiendahl, Reichardt & Nyhuis [6] define six types of production sites from the customer´s point of view, each with different targets, as shown in Figure 1. The *high-tech factory's* strategic main target is the technology, producing innovative products and technologies with the highest process quality and selling them to premium prices. A *responsive factory* with quick reaction times tries to optimize the factor time with the help of high-performance logistic in which the competitive advantage is the quick availability of products for the customer. Due to a low rate of automation and flexible worktime models, the *breathing factory* stands for a quick expandability, respectively reducibility of the factory output due to sales fluctuation and integration of new products. A *variant-flexible factory´s* focus lies on variant diversity and modular structures to be able to serve the market customer-individualized. In a *customer-specific factory*, each customer can configure and order his products as individually as possible. The last factory type is the *low-cost factory*, with the scope of cost-minimization due to a strict target cost management.

	Competitive factors					
Factory type	Time	Cost	Quality	Innovative capability	Speed of learning	Adaptility
Low-cost factory	○	●	○	○	◒	○
Responsive factory	●	○	○	○	○	◒
Breathing factory	◒	◒	○	◒	○	●
Variant-flexible factory	◒	◒	○	◒	●	●
High-tech factory	○	○	●	●	◒	◒
Customer-specific factory	●	●	●	◒	◒	●

● Important goal ◒ Medium goal ○ No goal

Figure 1 – Different targets depending on the factory type [6]

Considering strategic roles of production sites, individual targets can be derived. These targets in general define desired future states which can be achieved as a result of improvement measures [7] and are part of a hierarchical target system [8]. This target system connects strategic goals and their sub-targets, which are necessary to achieve the strategic goal and can influence each other in a neutral, complementary or contradictory way [9]. In this context, performance measurement systems (PMS), a set of metrics, track the degree of target attainment to quantify the performance [10]. Performance measurement is often defined as the "process of quantifying the efficiency and effectiveness of action" [10]. The efficiency describes the degree of meeting the required targets, the effectiveness quantifies the economic use of resources to achieve these targets [11].

In the past decades, PMS have evolved from financial instruments with solely financial metrics to *balanced systems* enabling a holistic performance evaluation [12]. The set of metrics, which are implemented, have the task to enable the proactive, forward-looking consideration of performance and shall improve controllability and manageability.

Notably approaches of PMS for production networks are the *supply chain operations model* (SCOR-model) [14] and the *Supply Chain Balanced Scorecard (*SCBSC) [15–18]. These approaches deliver basic frameworks for the performance evaluation of production networks, as shown in a combinatory approach of these two models to develop a supply chain performance measurement system (SCPMS) extending them on a sustainability-perspective [19].

What these systems have in common is the lack of hierarchical connection between network level and production-site-level, as well as the missing consideration of individual, multi-criterial and potential divergent target systems of the different sites.

Common approaches of decision making considering multi-criteria dimensions are counted to the class of multi-criteria decision making (MCDM) [20]. The main-target of these approaches address the evaluation of alternatives taking individual and divergent target systems with varying importance of different dimensions into account.

A major approach of MCDM is the Analytic Hierarchy Process (AHP), which uses pairwise comparisons relying on the judgement of experts or subjective assessment with the aim to derive priority scales [21]. Using pairwise comparisons, different alternatives can be evaluated due to their advantages and influences over the target system, as in this approach the performance evaluation of a production network. Another advantage is the integrated consistency check of the results, which ensures a consistency of the pairwise comparison and the resulting criteria weights.

Summarized, the application of the AHP allows the rating of different network configurations and improvement measures due to a performance measurement system considering divergent and hierarchical structured target systems.

The effects of improvement measures and different network configurations on the individual performance measures and the resulting performance of production networks underlie *dynamic factors, which are not pictured by an analytical approach of the AHP***.** Current research approaches do not consider these dynamic factors. Furthermore, there is an insufficient merging of the implementation of a consistent, completely connected performance measurement systems (PMS), which is also considering individual target systems (resulting in different strategic roles of sites).

The developed approach addresses these research gaps by developing a methodology of evaluating the performance using a developed PMS. To regard the dynamic factors, the approach is embedded into an agent based simulation model.

Based on the structure of global production networks, the concept of agent based simulation (ABS) is suitable for simulating their processes. The ABS splits complex systems into constituting units, the so-called agents. These agents follow specific rules to interact with other agents and their environment. The big advantages of ABS is the ability of picturing heterogeneous behaviour in a complex system [22] and the detection of emerging effects which are usually difficult to detect [23]. Because of these reasons, the ABS was implemented in various approaches and concepts of planning and controlling production networks [24].

3. METHODOLOGY

To evaluate the performance of production networks considering individual target systems, the developed methodology will be discussed in the following sections. Section 3.1 shows the methodology of evaluating the performance based on a PMS using MCDM. Section 3.2 covers the integration of this approach into an agent-based discrete event and unitized simulation model (ABSM) to allow dynamic examination of different network-configurations as well as effects of improvement measures to support strategic decision making.

3.1 Performance evaluation of global production networks

The framework of the performance evaluation is based on a hierarchical structured performance measurement system, which is shown in Figure 2. The network performance is divided into the different production sites, which are following their individual target systems. In this approach, five target dimensions are defined, which are sub-divided into sub-targets. The target dimension *sustainability* is divided into the environmental, the social and the economic sustainability. The *cost-dimension* and the *process-dimension* are divided into sub-targets concerning production, logistics and quality. The *quality-dimension* consists of process- und logistics-quality. *Resilience,* the ability of coping with change, is differentiated into the proactive and a reactive sub-targets robustness and agility [25].

To evaluate the performance of the sub-targets, performance measures are defined. These can be individualized and adopted to the specific use-case and serve the quantification of the targets. In Figure 2, the environmental sustainability is pictured, inter alia, by the percentage of renewable energy used on a production site, the recycling rate and the emissions of greenhouse gases (GHG).
The methodology to evaluate the network performance is undertaken bottom-up and is structured in five steps.

In a first step, linear target corridors (LTC) by defining minimal (x_{min}) and maximal values (x_{max}) for the performance measures will be implemented. Within these corridors, the degree of target attainment (DoT) can be calculated based on the expression, as shown in Figure 2 and Equation (1). The optimization direction is considered, too.

$$DoT = \frac{x - x_{min}}{x_{max} - x_{min}} \quad (1)$$

The second step is evaluating the performance of the sub-targets by calculating the average value of the performance measures' degree of target attainment (DoT_i) meaning each performance measure is equally weighted.

$$Performance = \frac{\sum_{i=1}^{n} DoT_i}{n} \quad (2)$$

The third step consolidates the sub-targets to the target dimensions. In this step, individual target systems are taken into account by using the AHP to define the weights of each sub-target. The performance of the target system is calculated by summing up the products of weights (w_i) and their performances of the sub-targets (p_i), as shown in equation (1):

$$Performance = \sum_{i=1}^{n} w_i p_i \quad (3)$$

The approach to define the performance of the production sites is similar to step three, using the AHP and the pairwise comparison to define the weightings enabling the performance calculation of the site.

The fifth step cumulates the site-performances to the network-performance by building the average, which can be adopted easily to an AHP at this level as well. But the described approach aims to focus on the pairwise comparison of the AHP to the strategic most relevant levels, which are the target- and sub-target-dimensions.

Summarized, the shown approach follows a bottom-up-methodology starting at defined performance measures consolidating them to the network performance while taking strategic roles of production sites and their individual target systems into account. Based on the fact that measures underlie dynamic volatility, the shown approach is embedded into an agent-based, discrete event and unitized simulation model, which enables the user to adopt the model at runtime to evaluate the cause-effect-relationships of improvement measures and changes of the network-configuration on the holistic network-performance.

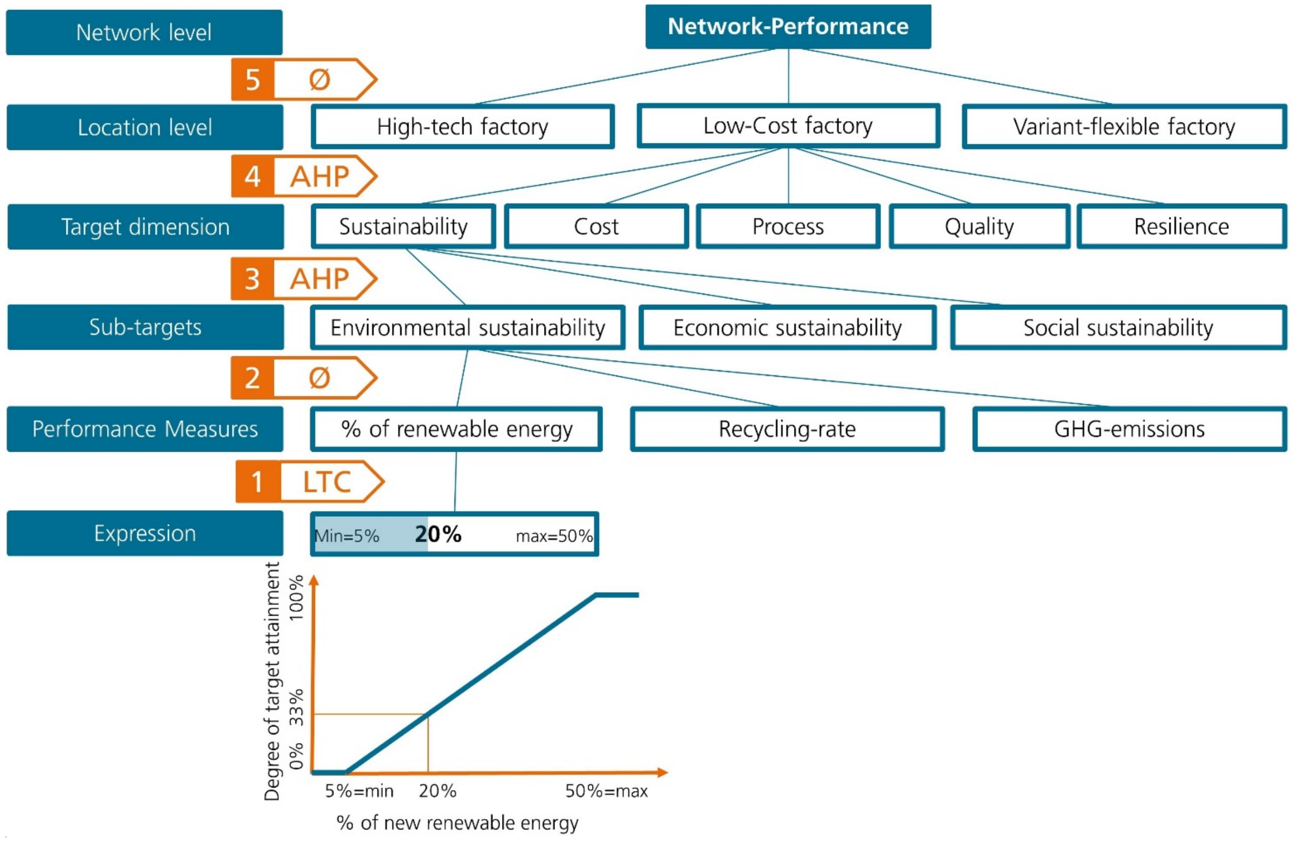

Figure 2 – The developed Performance Measurement System and the bottom-up-methodology of evaluating the Network-Performance

3.2 Integration into the simulation model

The simulation model itself contributes to *mapping the processes, generating and aggregating data, compressing and interpreting the generated data to calculate the network-performance in a dynamic environment.*

Starting point of integrating the methodology shown in chapter 3.1 is the individual configuration of the production network itself. Therefore, the hierarchical structure (Figure 3) "process – site – network" is regarded. A relatively fast adaption of the simulation model is enabled through modularizing core processes into defined building blocks, the agents. On process-level, several agents are defined to model production processes, internal transports, quality checks and storage of products. With these modules, the user can model the internal supply chain of a site. The sites are connected with transport agents, delivering products to the customers or between the production-sites. With defined target-systems of site roles, which are derived from their strategic role as shown in Figure 1, the individual weighting of target dimensions is pre-set. These pre-sets can be adopted by the user due to the AHP-process in the simulation model.

Based on input data like process-data (e.g. process and delivery times, quality rates), costs (e.g. cost rates of employees, goods, and others) and markets (e.g. sales numbers of the products) the simulation model generates data on runtime and calculates and implements the processual measures into the performance measures of the PMS.

These are interpreted by using the methodology of 3.1, compressing the data using the linear target corridors and the AHP and defining the network performance as a last step.

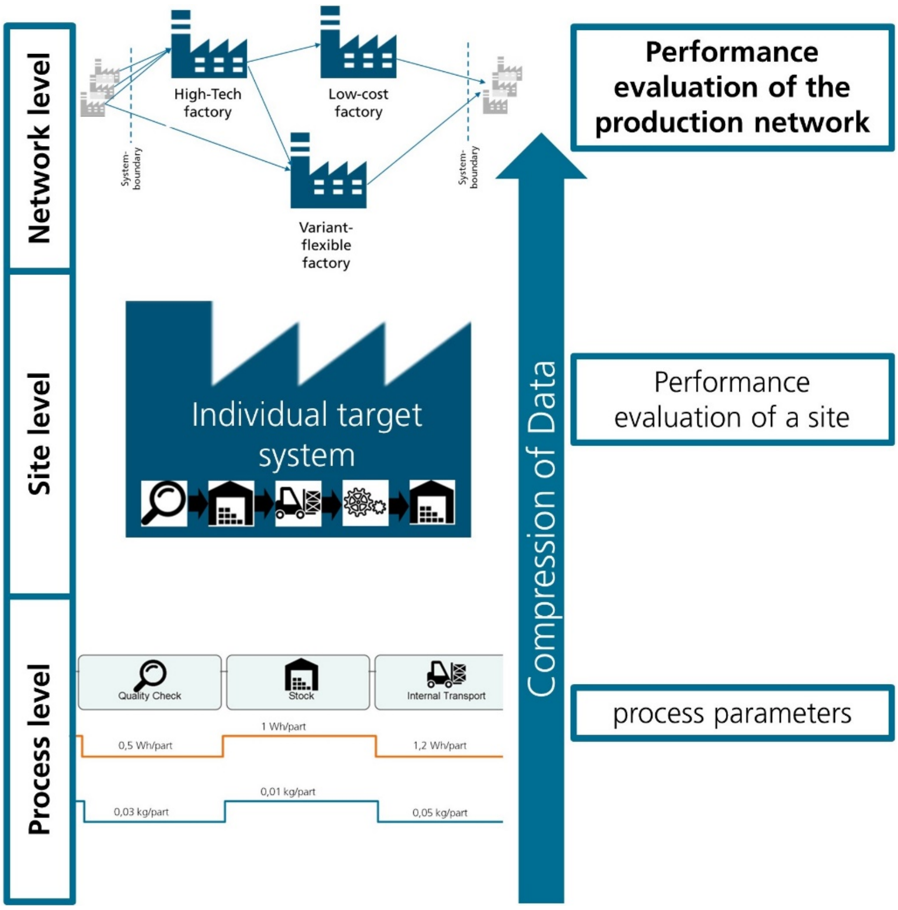

Figure 3 – Hierarchical structure and outputs of the agent-based simulation model

The detail of modelling the processes is oriented on the methodology of Value Stream Mapping (VSM).

To picture parameters and indicators of sustainability management, extensions of VSM are discussed in scientific areas to track the energy consumption and factors of sustainability like the greenhouse gas (GHG) emissions on each process [26, 27].

Figure 4 illustrates the integration of these factors in the ABS-model on each process step, which allows the evaluation of different improvement measures also considering sustainability, like using another type of transport system (internal and external) or changing the network configuration which could reduce transport distances.

In this example, the energy intensity and the amount of CO2-emission is tracked on each process step. For a quick change of setups, benchmarks for transport types are implemented in the simulation model allowing a fast change and evaluation of them.

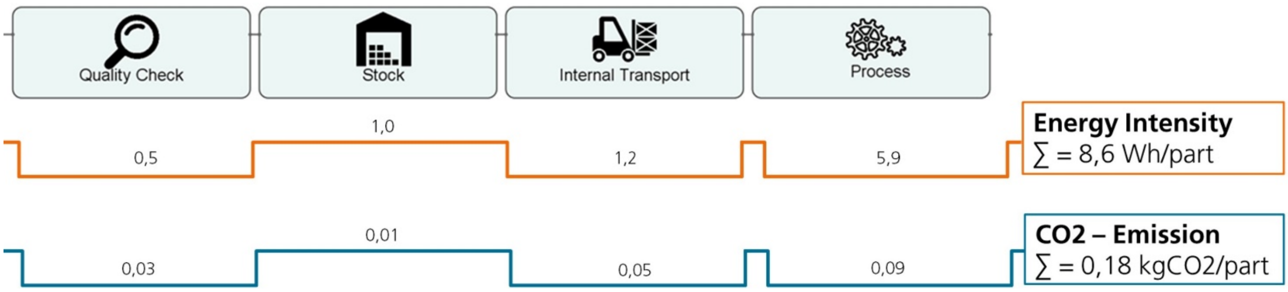

Figure 4 – Integrating sustainability-measures into the simulation model

4. CONCLUSION

In this paper, a methodology of evaluating the network performance supporting the strategic management and decision making of global production networks was presented considering individual and divergent target systems.

The main target during the development of the methodology was the suitable compression of data, which is generated on the different sites, to evaluate the performance of the network. This compression and preparation of data is a huge challenge for companies, which are usually generating sufficient data, but lack of using them in a purposeful, efficient and effective way. This problem is strengthened due to technological progresses, which allows tracking huge amount of data.

The subjective performance evaluation is realized by using the AHP, which defines weights on different target dimensions and sub-targets depending on the factory role. This enables the user to take individual strategies into account when evaluating the performance and investigating the effects of improvement measures and network-configurations.

To model dynamic effects of the methodology and to offer an user-friendly and agile environment, the methodology was implemented into an ABSM mapping the different levels from production level, site level and the network level as well as the performance evaluation of the sites and the network. The main task of the simulation model is to support the identification of improvement potentials and to evaluate improvement measures before their implementation to prevent wrong decisions.

In general, the shown methodology supports the strategic decision making and the management of production networks.

In the next steps, the developed methodology will be implemented in industrial use-cases to show the results and the possibilities to evaluate the performance of production networks and to support strategic decision making.

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