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Value-focused design of lean production systems based on a system dynamics approach

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Abstract

Lean principles are the central core of many industrial companies for improving their production system. In order to be able to optimize their manufacturing and logistics processes, companies have to choose the most suitable lean principles to solve problems or to reach their target state. To solve this decision problem, it is important to identify objectives based on values of the decision-maker and to determine effects of lean principles and objectives. This paper presents a value-focused thinking driven identification of objectives and a system dynamics approach for understanding the interdependencies and dynamics of lean principles and objectives. This provides a transparency and better understanding for these interactions for the decision-maker in the decision-making process. Based on this knowledge, the most effective lean principles for the design of the production system can be chosen and successfully applied.

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Keywords: Lean principles, design of production systems, value-focused thinking, system dynamics

1. Introduction

Due to the continuous globalization, shorter product life cycles and diversified customer demands, it is crucial for manufacturing companies to optimize their production system to maintain a long-term and sustainable competitiveness [1]. An optimization potential arises especially for manufacturing companies through a continuous and holistic integration of increasing logistics activities in the overall production process. Research studies show that the holistic integration and continuous optimization of manufacturing and logistics processes are the key to reduce production costs up to 25 %. [2] The importance and the overall advantages of the integration are reflected by a current survey among manufacturing companies. Therefore, 94 % of the companies identify the integration of manufacturing and logistics processes as an efficiency advantage for their production system. [3]

The integration of manufacturing and logistics processes and their corresponding systems leads to lean production systems. This integration is implemented through the application and adaption of lean production principles for logistics processes to eliminate the parts of processes, which have no value from a customer point of view. [4–7] Similar applications and adaptions of the principles of the lean philosophy can be recognized within other scientific approaches e. g. information technology process models and manufacturing support process analysis. [8,9] The adaption of the lean philosophy for the design of logistics processes supports the current market-driven requirement of a high performance at the least possible costs. Companies are able to gain a competitive advantage and effectively optimize their processes by meeting these requirements, through the design of lean production systems. [7,10]

The effective design of lean production systems is on the one hand characterized by the underlying principles of a continuous orientation on processes, which are value-added in terms of the lean philosophy. On the other hand, the design depends even more on the effective selection of suitable lean methods and begins with an analysis of the current state. This analysis is very important for the entire decision-making process and is often a problem for the decision-maker. [11] Furthermore the selection of lean methods differs from company to company due to individual problems, subjective objectives of decision-makers and different circumstances of the company. [4]

To solve these problems, this paper presents a value-focused driven approach after Keeney [12] for the identification of objectives, the effective design of lean production systems and their integration in an exemplary system dynamics model after Sterman [13]. The underlying system of objectives for a value-added production system was introduced by Drews et al. [14]

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2. System dynamics

2.1. Thinking in systems

System dynamics was developed in the late 50's of the 20th century at the Massachusetts Institute of Technology (MIT), under the leadership of Forrester. [15] Due to the primary application in industrial companies, Forrester used initially the term "Industrial Dynamics". [16] Considering the ability to apply this approach to a variety of possible fields, the todays customary term "System Dynamics" enforced later. [17]

The investigation of systems is the subject of various scientific disciplines such as physics, biology, sociology and engineering. [18] Von Bertalanffy describes the constitutive elements of a system in his system theory with at least two interrelated elements that results in a specific structure. [19] The simplest form of the relationship between two elements is a one-sided cause-effect relationship. In feedback relationships, the influence of an element reacts on this. If this happens indirectly, through the interaction with another element, there is a feedback loop. In addition, there is the possibility that elements directly influence to their own state. [20]

Based on these common definitions of systems and their components, a general understanding of systems is established among the various scientific disciplines (see Fig. 1).

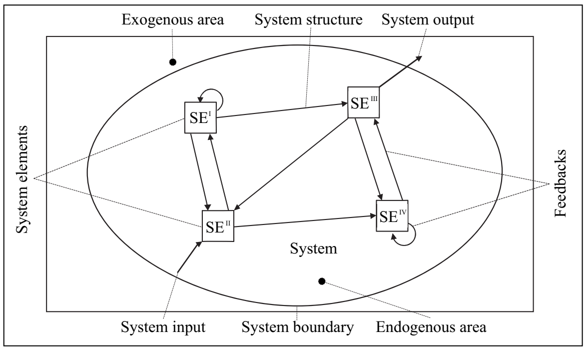

Fig. 1. General understanding of the basic components of a system [21]

Westkämper shows that the system "production" is a complex and socio-economic system, which consists of partly autonomous elements or subsystems. [22] System dynamics considers these dynamics relations and interdependencies on a strategic level and was therefore chosen as the basis modeling approach to gain a deeper understanding of the effects of the identified value-focused objectives and lean principles. [23]

2.2. Complexity in systems

The term "complexity" has a variety of different meanings in system thinking. Due to its relevance, it is essential to question what exactly it means and what effects it has on decision-making behavior. In common usage, a situation is considered to be complex, if it is difficult to overview all interdependencies. This type of complexity is directed to the number of elements and their relationships with each other and will be referred as a structural complexity. [24]

The complexity arises especially through the interconnectedness of the system elements. If the problem is characterized by a high structural complexity, the challenge is to find the optimal constellation of variables. [25] However, complexity can also occur in a low structural degree of complexity. [26] The reason are not the interdependencies in the system, but the frequency and intensity of changes over time of the system structure. In these cases, one speaks of dynamic complexity. The differentiation in a structural component and dynamic component of complexity is agreed upon within the scientific community and can be found in various disciplines e. g. the analysis of remanufacturing [27], product complexity [28], ecological transparency [29], production logistics [30], effects on organizations [31] and effects on companies [24,32]. Derived from this general understanding and based on the nature of system dynamics, a classification of systems in terms of complexity and potential applications of system dynamics can be evaluated (see Fig. 2).

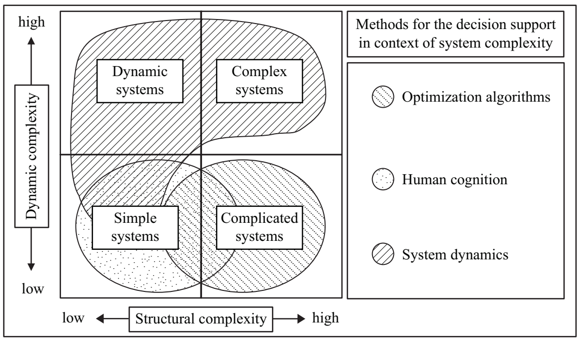

Fig. 2. Complexity of systems and application of System Dynamics [25,33,34]

2.3. Structure and behavior of dynamic systems

The main aim of system dynamics is to show the system behavior on the basis of the interaction of the system components. From this endogenous principle, it follows that the number of the system's exogenous variables should be kept as low as possible. [35] A variable is exogenous, if its expression is given and is not explained or derived from the system's behavior. Endogenous variables are explained by the components of the system. [36] The question of the optimal number of variables cannot be answered conclusively. A high number of variables ensures, that the model is more able to reflect the reality, but each additional variables also increases the complexity of the model. This trade-off is also known as "Bonini's paradox". [37]

System dynamics is based on the assumption, that the system behavior results mainly from the endogenous interactions of the system elements. Furthermore, any system behavior can be attributed to two basic forms (positive and negative feedback loops) or to a combination of these two basic forms. [13,38] In addition to the two basic forms, more typical types of behavior occur, if e. g. existing time delays, predetermined or desired goal values or restricted factors are implemented (see Fig. 3). The implemented time delays e. g. cause corrective actions to continue even after the state of the system reaches its desired goal, forcing the system to adjust too much, and triggering a