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Towards quantitative factory life cycle evaluation

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Abstract

Manufacturing companies face the challenge of understanding and improving complex factory systems in order to stay competitive in a turbulent environment. Interrelated and overlapping life cycles of products and physical factory elements (e.g. machine tools, technical building services, building shell) are challenges to be handled in factory planning and operation. This work discusses both qualitative and quantitative factory life cycle models, analyzing addressed sustainability goals. Due to the lack of quantitative life cycle description models on higher system levels, a concept for aggregating life cycle models from shop floor up to site level is developed. The concept is consequently applied in a case study where cost curves are calculated over the factory's life span and are aggregated to support factory planning and operation.

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1. Introduction

To successfully compete in the market, companies need their factories to be flexible and changeable in order to be able to actively shape the required change processes. Economic goals are no longer the only criteria that need to be considered, as stricter legislation and customer awareness are forcing production to address environmental and social targets as well. The special challenge for factory planners lies in the fact that the life span of factory buildings as well as investment goods such as production machines or technical building services (TBS) exceeds the production period of the products. This results in numerous problems during planning and operation of factories, which need to be addressed.

This paper assesses the applicability of existing approaches to describe the life cycle behavior on different factory levels. As indicated by SCHMIDT ET AL., there is a lack of quantitative life cycle evaluation models on plant level [1]. Hence, a framework is proposed which aggregates different life cycle models to enable factory life cycle evaluation.

2. The factory as a system

The factory has to be considered as a complex socio-technical system [2]. It is for this reason, that an evaluation of the entire factory as one object is not applicable [3]. The factory as a system has to be differentiated in its factory elements and organized within a hierarchical structure. A generic description of all factory elements has already been provided by NYHUIS ET AL. [4]. For the purpose of structuring the factory elements, a top-down as well as a bottom-up approach can be conducted.

In the top-down analysis, the vertical breakdown of the factory in factory levels is a feasible approach to provide a hierarchical structure to the inherent objects. According to systems theory, a superior factory level includes subordinated levels, whereas the degree of detail decreases with increasing hierarchy levels [5]. As a compromise between level of detail and unequivocal allocation of factory elements to their related factory levels, a differentiation of the factory as a system into site, plant, section and workstation according to WIENDAHL ET

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AL. is employed [6]. Additionally, a horizontal segmentation of the factory in factory fields is performed, as displayed in Fig. 1. According to HEGER, these fields are defined as technology, organization and space [3].

In contrast, the bottom-up analysis originates from the single factory element. On this low level, the properties and interdependencies of factory elements can be analyzed in detail and subsequently be integrated upwards on a more abstract, but nevertheless coherent level [7]. The bottom-up analysis is especially suitable for a countervailing check of congruency and plausibility in a top-down model. Especially for validating factory life cycle models by utilizing case studies, the bottom-up analysis is of interest [8].

factory levels \ factory fields	technology	organization	space
site level	▪ building services - centers	▪ hierarchical structure	▪ property ▪ site development plan ▪ outdoor areas
plant level	▪ building services – distribution facilities ▪ Information techn.	▪ production concept ▪ logistics concept ▪ structure	▪ layout ▪ building form ▪ building structure ▪ shell / appearance
section level	▪ storage facilities ▪ transportation facilities	▪ work organization	▪ development
work-station level	▪ production techn. ▪ production facilities ▪ other facilities	▪ quality management concept	▪ workplace design

Fig. 1. Factory levels and factory fields as top-down structuring approach for factories as systems with exemplary factory elements; adapted from [3, 6].

3. Factory life cycle models

The factory is situated in a field of tension between the push and pull factors that require a high changeability [6]. The technology push by the availability of new and more efficient processes and tools as well as the market pull consisting of e.g. cost pressures and customer expectations can exemplarily be mentioned [9]. The individual layers and elements of the factory as a system are thus subject to dynamic changes and undergo individual life cycles. Fig. 2 shows qualitatively how the life cycles of selected factory elements superimpose.

Similar to the illustrated utility curves, all elements have varying cost and ecological impacts over the life cycle. In general, not only the initial investments apply, but in particular during the use phase costs accrue resulting from operation, maintenance or component replacement, demand of consumables and energy etc. Costs are evaluated by the use of Life Cycle Costing (LCC), while the environmental impacts are assessed based on a Life Cycle Assessment (LCA). In combination with the Social Life Cycle Assessment (S-LCA), the Triple Bottom Line of sustainability is addressed.

In the unsettled environment of the factory it is the challenge to adapt and develop these curves to reach an economic and ecological optimum. For this purpose, the interrelated disciplines of e.g. investment appraisal, change management and the evaluation and measurement of flexibility are important analyses in order to support the spanning life cycle evaluation of factories [10, 11]. Against this background, a selection of methods for life cycle evaluation and description for the different factory levels according to Fig. 1 is provided in the following.

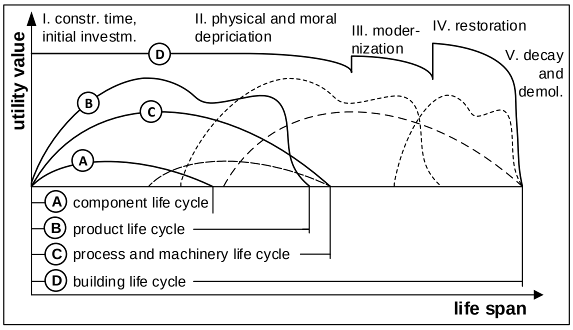

Fig. 2. Relations between life cycles of factory elements; adapted from [12].

3.1. Site level

A production site can consist of different locally interdependent factories. Research in the area of life cycle evaluation on site level was funded by the European Commission in the Pathfinder project. In the course of this research project, models describing the life cycles of single factories and interactions with their environment and infrastructure were developed. The considered goals of these models involve the economic, ecological and social dimension. Results of this project are a “Pathfinder Vision and Roadmap”, which contains the qualitative description of potentials that could arise from a comprehensive factory life cycle evaluation [13].

A life cycle model of the production site which integrates the manifold existing elements was developed by HARTKOPF. The focus of the model lies on capacity and technology requirements for the development of the site. In this matter, the capacity restrictions of machines, equipment and manufacturing facilities are integrated on site level. According to the current phase of their life cycles, recommendations for action are derived for achieving future economic goals of the entire site [14].

3.2. Plant level

On plant level, the production and logistics concept, technical building services as well as the building shell can be highlighted according to the horizontal differentiation of the factory (see Fig. 1). These factory elements are interdependent of each other which could result in difficulties to estimate priorities of improvement measures [15].

In the literature, various models describing the life cycle on plant level can be found. Originating from SCHMENNER, diverse phase models of the factory life cycle have been developed [16, 17, 18]. To give an example, MÜLLER ET AL. distinguish the life cycle phases of factory planning, construction, commissioning, factory operation and shutdown [19]. The objective of these process models is to identify the relevant influencing factors for each phase of the factory life cycle, in order to achieve a sensitization of the planning staff