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Life cycle oriented evaluation of flexibility in investment decisions for automated assembly systems

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ABSTRACT

Due to fast changing market requirements and short product life cycles, flexibility is one of the crucial characteristics of automated and partly automated assembly systems besides purchasing and operation costs. Since the life cycle of an assembly system is longer than the one of the assembled products, flexibility enables an assembly system to adapt to future product requirements as well as production scenarios. The approach proposed in this paper strives for a systematic and economic measurement of flexibility in investment decisions. It offers methods and key-figures supporting the investment decisions for automated assembly systems. The right levels of flexibility and automation of an assembly system are evaluated by using a set of potential future scenarios of the system's life cycle. Based on two new key-figures called Return on Automation and Return on Flexibility, the approach allows comparing different configurations of an assembly system and therefore supports well-informed investment decisions.

1. Introduction

Companies in manufacturing industries are confronted with the challenges of an increasing market dynamic, an increasing competition and an uncertain environment, caused by globalization of the markets and economic crises. Shorter product lifecycles, more product variants and volatile product demands and a concurrent increasing product complexity, are characteristic consequences for companies in this market environment (Schuh et al., 2004, 2005; Seidel and Garrel, 2011).

In this context, the ability to adapt to the changing requirements is becoming an important competitive factor. A continuous adaptation of the manufacturing system to the market requirements is necessary. Since future requirements for the manufacturing system cannot be forecasted exactly, a proactive adaptation of the system is rarely possible and the manufacturing system is not optimally configured for the upcoming situation. Therefore, manufacturing flexibility is an important goal to achieve in the early planning phases of the system (Schuh et al., 2004, 2005). In addition low production costs are an important factor for competitiveness. The automation of manufacturing systems is one solution to reach this goal. While automation usually effects a reduction of flexibility of the manufacturing system, a trade-off has to be made between these two goals.

The approach proposed in this paper, attempts to give support in identifying the right trade-off between flexibility and automation in investment decisions for automated assembly systems. Automated assembly systems are an example for systems with high investment costs on the one hand and the need for flexibility over the system's life cycle on the other hand. The approach is intended to be used in early planning phases of automated assembly systems. Chapter two of this paper illustrates the required types of flexibility of assembly systems. Challenges in the economic evaluation of flexibility and existing approaches are summarized in chapter three. In chapter four the approach to a life cycle oriented evaluation of flexibility in investment decisions for automated assembly systems is introduced. In chapter five an industry case is presented. Chapter six concludes this paper.

2. Flexibility of assembly systems

The economic and life-cycle oriented evaluation of flexibility in investment decisions, requires a clear definition of the necessary types of flexibility provided by assembly systems. As there are numerous approaches for the description and measurement of manufacturing flexibility, a common definition of manufacturing flexibility and its various types in literature is not available (De Toni and Tonchia, 1996).

Flexibility acts as a "counterbalance" to uncertainty (Newman et al., 1993). It describes the ability of a manufacturing system to

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cope with unforeseen changes. The two main types of unforeseen changes which necessitate flexibility are external changes (demand, supply) and internal changes (system breakdown, lack of material, delay). Manufacturing systems with a high degree of flexibility adapt to new situations, caused by external or internal changes, quickly and without significant, new investments (Chryssolouris, 1996; De Toni and Tonchia, 1996). Chryssolouris (1996, 2006) suggested that flexibility of a manufacturing system should be evaluated by the expected costs necessary for the adaptation of the system. There are numerous approaches to classify flexibility into different types (e.g. Browne et al., 1984; Sethi and Sethi, 1990). In the next step the main types of flexibility for assembly systems are derived from the external and internal requirements for the assembly system.

As in most industrial sectors, the life cycle of an assembly system is longer than the one of the assembled products. Thus, the necessity for flexibility of automated and partly automated assembly systems is evident. Furthermore, the necessity is intensified by an increasing frequency of product changes caused by shorter product life cycles. These challenges can be met by a type of flexibility, which allows the set of products to be changed easily (Schuh et al., 2004).

Frequent product changes result in a mass of different variants of the same product type. In addition, the complexity of the product variants increases. Thus, the assembly system has to assemble different variants and types of products at the same time to remain competitive (Schuh et al., 2004).

Volatility of the demand during a product life cycle is typical for most markets. To enable profitable assembly at different volumes, this challenge has to be counterbalanced by flexibility (Schuh et al., 2004).

With regard to these requirements three main types of flexibility seem to be adequate for the classification of the assembly system flexibility (Fig. 1) (Browne et al., 1984; Suarez et al., 1991):

- *Product flexibility* describes the ability of the production system, to produce a changed set of products without serious updates and replacements of the present resources.
- *Mix flexibility* describes the ability of a system to produce a number of different products at the same time.
- *Volume flexibility* describes the ability of an assembly system to vary the volume of products without remarkable consequences on production costs.

3. Challenges in economic evaluation of flexibility

The fact, that no commonly accepted approach to the evaluation of the flexibility of manufacturing systems exists, shows the need for new decision support methodologies in industry. The multi-dimensionality of flexibility and the lack of direct measures of flexibility, make an evaluation of manufacturing flexibility difficult (Cox, 1989). This is particularly true for the financial or economic evaluation of flexibility. While the investment in a flexible manufacturing system is easy to quantify, the financial benefits of an increased manufacturing flexibility are hard to determine (Zäh et al., 2006). Based on a review of existing approaches for the evaluation of manufacturing flexibility, the necessity for a life cycle oriented evaluation of assembly system flexibility in investment decisions is going to be derived.

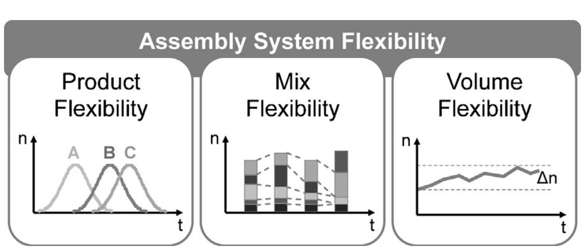

Fig. 1. Main types of assembly system flexibility.

Schuh et al. (2004) developed a system of key figures for the evaluation of product, mix and volume flexibility. The system is able to measure the flexibility on different organizational levels (workstation, production line and production system or production networks). However, a detailed monetary evaluation of flexibility is not possible.

Abele et al. (2006) extended in their approach the net present value method by real options analysis for the evaluation of flexibility. The approach considers the temporal structure of decision relevant cash flows. The approach by Zäh et al. (2003) is another example for using real option analysis in flexibility evaluation. Since real option analysis presupposes the existence of a market traded financial option, with the same cash flows over time, the usage of the approaches is very restricted.

Alexopoulos et al. (2007) developed the DESYMA approach for the determination of the flexibility of a manufacturing system by statistical analysis of the estimates of the manufacturing system's lifecycle cost. The estimates are calculated with discounted cash flows over a time horizon and for different market scenarios, using a linear program. The approach does only consider possible adaptations caused by different demand volumes. Georgoulias et al. (2009) integrated the DESYMA approach into a toolbox approach for flexibility evaluation.

The approach for the flexibility evaluation by Reinhart et al. (2007) is divided into three steps (definition of alternatives to evaluate, modeling the future with uncertain states of the environment, determination of the most economic alternative). Using discounted cash flows for the economic evaluation the approach just considers the volume flexibility.

Rogalski and Ovtcharova (2009) developed the ecoFLEX approach for the comparison of different manufacturing systems regarding their flexibility. The comparison is based on a linear program, calculating "flexibility areas", considering the mix and volume flexibility of a system. Monetary parameters are not considered in detail.

The approach developed by Rühl (2010) strives for the economic evaluation of manufacturing in the design phase, considering the flexibility and risk criteria. The approach is not life cycle oriented and only considers volume and mix flexibility.

Table 1 summarizes the characteristics of the relevant approaches introduced in this chapter. None of these approaches totally fulfills all necessary requirements for a life cycle oriented evaluation of flexibility in investment decisions for automated assembly systems. The following chapter introduces a new approach for an economic evaluation of flexibility, based on two main key-figures.

4. Life cycle oriented evaluation of flexbility in investment decisions

As future flexibility of assembly systems is determined within the investment decision and therefore at the beginning of the life cycle, the approach of a life cycle oriented evaluation of flexibility aims to provide support for investment decisions, for assembly systems, in the early phases of the systems design. The approach is based on two main key-figures. The first key-figure is the Return on Automation (ROA) and the second key-figure is the Return on Flexibility (ROF). These key-figures and the approach itself will be detailed in the following paragraphs.