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DSM-BASED EVALUATION OF ASSEMBLY MANUFACTURING RESOURCES

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ABSTRACT

Due to the increasing turbulence of the manufacturing environment, the number of reconfigurations on Assembly Manufacturing Resources (AMRs) rises. Hence, evaluation of reconfigurability is becoming more and more important. Nevertheless, no structured key performance indicator (KPI) system exists for the evaluation yet. Therefore, in this paper an existing DSM-based evaluation methodology is upgraded. For these reasons two categories of KPIs are defined in this paper: structural and economic KPIs. Structural KPIs and their interactions are described, economic KPIs structured, their relations shown and implemented into a KPI system. The KPIs facilitate for instance investment processes. In order to support the use of the methodology, a software tool to execute the methodology and to gather the relevant KPIs was developed. An example states the determination of chosen KPIs.

Keywords: Evaluation, Production Resource Modelling, reconfigurability

1 INTRODUCTION

Today's manufacturing environment changes rapidly. Product life cycles are shortening, companies face high international pressure, customer requirements increase and technological innovations accelerate (Abele et al. 2006, Koren et al. 1999, Zaeh et al. 2009). These factors cause among others need for reconfiguration. Consequently, the number of reconfigurations on assembly manufacturing resources (AMRs) increases, as existing AMRs are due to cost limitations not flexible enough to handle changes in the environment. Hence, it is important to evaluate the reconfigurability of AMRs. In this paper reconfigurability (Wiendahl et al. 2007) is defined as the capability of AMRs to implement innovations (e. g. new products or production technologies) without large expense (e.g. costs).

The structure of a methodology for evaluating AMRs has already been presented (Zaeh et al. 2010). It comprises five steps: influencing factors are identified, AMRs modelled by DSMs, the factors mapped to the models, reconfigurations forecasted and visualized by graphs and evaluated by key performance indicators (KPIs). Zaeh et al. (2010) give various KPIs to evaluate reconfigurability (e. g. employee capabilities needed, total costs). Nevertheless, KPIs are not structured since relations between them are not shown. Moreover, many KPIs for evaluating graphs and DSMs (see e. g. Kreimeyer 2010) are not directly applicable, since many of them are not meaningful for non-directional graphs, as they result in zero or uniform values (Biedermann & Lindemann 2011). Therefore, this paper presents DSM-based KPIs for evaluating reconfigurability of AMRs. After presenting the structure of the existing methodology in Section 2 and the scientific approach in Section 3, the two categories of KPIs (economic and structural KPIs) are explained in Section 4. Furthermore, a structured KPI system for the DSM-based evaluation of AMRs is introduced. Since planners of AMRs are supposed to use the methodology, an excel-based software tool was developed. Section 5 shows exemplarily the application of the tool and the KPIs.

2 METHODOLOGY FOR EVALUATING ASSEMBLY MANUFACTURING RESOURCES

The methodology to evaluate reconfigurability of AMRs consists of five steps (Zaeh et al. 2010, see Figure 1). AMRs considered are used in production, e.g. in automotive industry for welding. First (1), influencing factors are identified and forecasted. This step is executed to predict need for reconfigurations. Second (2), AMRs are modelled on component level (components are for example engines or pneumatic cylinders) using DSMs. DSMs are applied to show effects of adaptations on components on the whole AMR by modelling relations between components. Third (3), influencing factors are mapped to directly influenced components to show which components are immediately concerned and thus might have to be changed. Fourth (4), reconfigurations are displayed. Usually, not only directly affected components have to be reconfigured, as these components are in contact with additional components. These impacts are shown as graphs / trees, which display all changed, added, deleted or replaced components. The graphs are built up based on impact analysis (Lindemann et al. 2009). Since the model (DSM) changes due to added, replaced or deleted components, it has to be adapted. Fifth (5), various KPIs are derived from the graphs for evaluating reconfigurability (see Section 1).

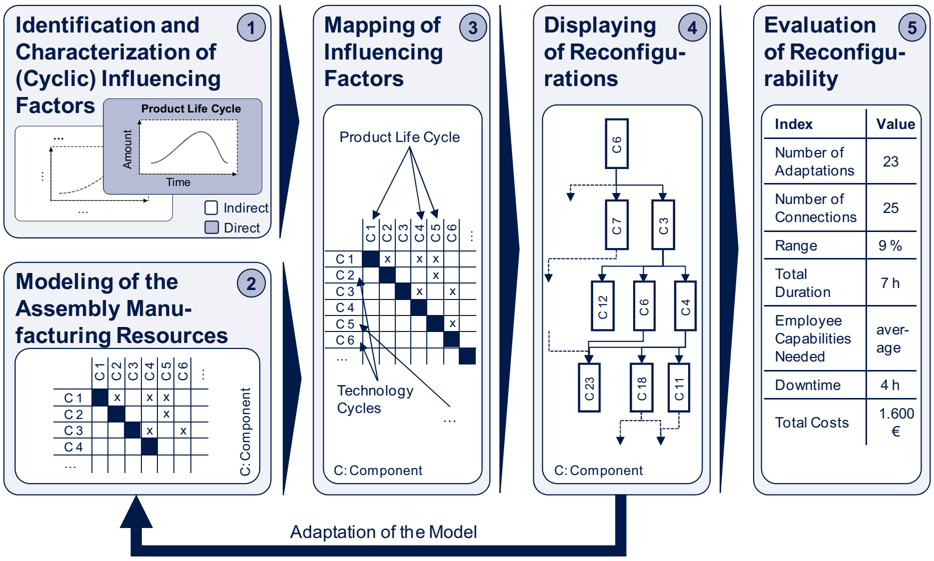

Figure 1. Methodology to evaluate reconfigurability of AMRs with exemplary figures and numbers (according to Zaeh et al. 2010)

3 SCIENTIFIC APPROACH

Evaluation of reconfigurability of AMRs is an important issue (e. g. in investment decision processes), as the number of reconfigurations rises. Existing evaluation methods for production resources (e.g. Milberg & Möller 2008, Heger 2007), examine a higher factory level (e.g. site or building level, see Wiendahl et al. 2007). In order to describe reconfigurability it is important to consider the structure of the AMR, which is not taken into account by existing methods. Since investment decision processes are almost exclusively based on monetary values, it is crucial to also consider economic elements as well. As KPIs were not structured, nor their interdependencies shown yet (Zaeh et al. 2010), this paper closes the gap.

Various graphs form the initial point for the evaluation in this paper. Figure 2 shows three necessary reconfigurations on an exemplary AMR and the graphs evoked (see step (4) in Figure 1). These graphs are either reconfigurations at different points in time or alternatives (see reconfiguration B1 in Figure 2) to execute a reconfiguration. The graphs specify the reconfigurations by displaying changed, added, deleted or replaced components.

4 KEY FIGURES AND KPI SYSTEM FOR EVALUATING ASSEMBLY MANUFACTURING RESSOURCES

In order to evaluate reconfigurability, two types of KPIs were defined: structural and economic KPIs (see Section 3). Structural KPIs base on the DSM of an AMR, on the graph of one reconfiguration or on both. Only the reconfigured components are considered when using the graph-based KPIs. Economic KPIs are generated based on the graphs and include additional data. Both, structural and economic KPIs, can be used to compare AMRs in an investment decision process or to compare reconfiguration paths (see alternatives A and B in Figure 2). The following sections explain the structured KPIs and the economic KPI system.

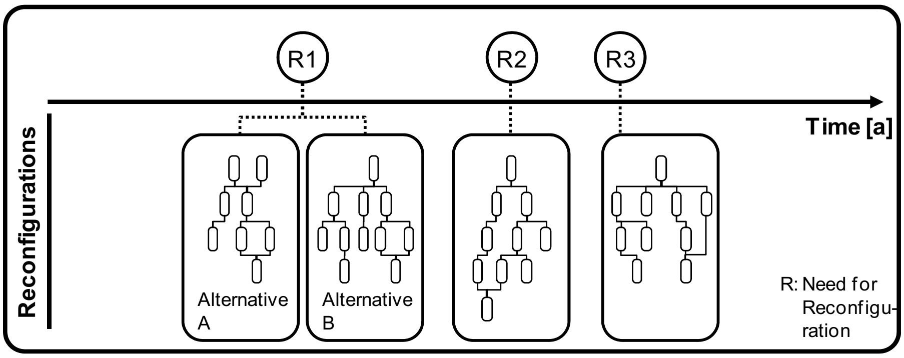

Figure 2. Various Reconfigurations in the Life Cycle of an Exemplary AMR

4.1 Structural KPIs

In order to evaluate reconfigurability of AMRs four structural KPIs are appropriate for the evaluation. These KPIs mostly depend on the trees that are derived from DSMs and only partly on DSMs. Table 1 presents the structural KPIs. They can also be scaled by relating them to the DSM of the ARM (e.g. "range" is the ratio between the number of adapted components and the total number of components).

Table 1. Structural KPIs

KPI	Description
Number of Adaptations	This KPI describes the number of components that have to be changed, added, deleted or replaced. Therefore, it is the amount of nodes in the graph.
Number of Connections	The number of connections is the sum of all edges in a graph. As it shows how many interactions exist between the components, it is an indicator for the complexity of the reconfiguration.
Depth	Depth specifies the number of steps of the graph. It is the longest branch of the tree. Hence, a high depth implies that long reconfiguration chains exist.
Snowball Factor	Snowball factor is the sum over all adaptations of the reciprocal of the distance from the initial adaptation (Kreimeyer 2010). It shows if the subsequent adaptations occur rather directly (frontloaded) or indirectly (backloaded).

In decision making and investment processes, costs are a core criterion. As costs are not considered in structural KPIs, it is crucial to also include economic KPIs when evaluating reconfigurability. These KPIs are presented in the next section.

4.2 Economic KPIs and KPI system

Eight economic KPIs were developed to evaluate reconfigurability, as they display various reconfiguration costs and durations during an AMR life cycle at different levels. These depend on each other and build upon each other. The KPIs are based on data from data bases or expert knowledge and data that is gathered while building up the graphs (see step (4) in Figure 1). Figure 3 shows the economic KPI system. Table 2 presents the KPIs and their relations.

Table 2. Economic KPIs

KPI	Description
Reconfiguration Costs/Component (see "Costs for Component A" in Figure 3)	This KPI consists of three elements that are summed: labour, material and machining costs (according to Zhang et al. 2006). Labour costs for carrying out reconfigurations are determined by multiplying the duration of the reconfiguration by the rate of the salary group of the staff. The rate depends on the qualification required to execute the reconfiguration. Duration and qualification required have to be collected when building up the graphs. The KPI material costs summarizes the costs for all materials needed to accomplish all reconfigurations on one component. Machining costs are costs for machines and tools necessary to fulfil the adaptation. This KPI is calculated by multiplying the machine hour rate by the duration the machine is needed. The machine hour rate depends on the employed machines.

Labour Costs	This KPI is the sum of all labour costs in one tree.
Material Costs	All material costs of all reconfigured components are added in this KPI.
Machining Costs	This KPI sums up the machining costs for all reconfigured components.
Duration of Downtime	This KPI represents the time needed for implementing all reconfigurations of one tree. During this period the AMR cannot be used for production. The duration equals the sum of all reconfigurations or less, if some can be carried out simultaneously. Hence, the shortest downtime is the longest reconfiguration time of single components, if all reconfigurations can be carried out simultaneously. The duration of downtime can be gathered according to the critical path method (Kerzner 2009).
Downtime Costs	Downtime costs are costs that are caused by not using the AMR value creating (according to Redecker 1969). This KPI is determined by multiplying the duration of downtime by an AMR specific downtime cost rate.
Costs for Reconfiguration	This KPI comprises all costs caused by one reconfiguration. Hence, downtime, labour, material and machining costs are summed up.
AMR Life Cycle Reconfiguration Costs	All reconfiguration costs caused in the life cycle of an AMR are merged by this KPI. Since reconfigurations are executed and their costs caused at different points in time, impacts on interest have to be regarded. This is taken into account by discounting the various costs for reconfiguration and summing them up. Thus $NPV_{Reconfiguration}$ is built up (Zaeh et al. 2010).

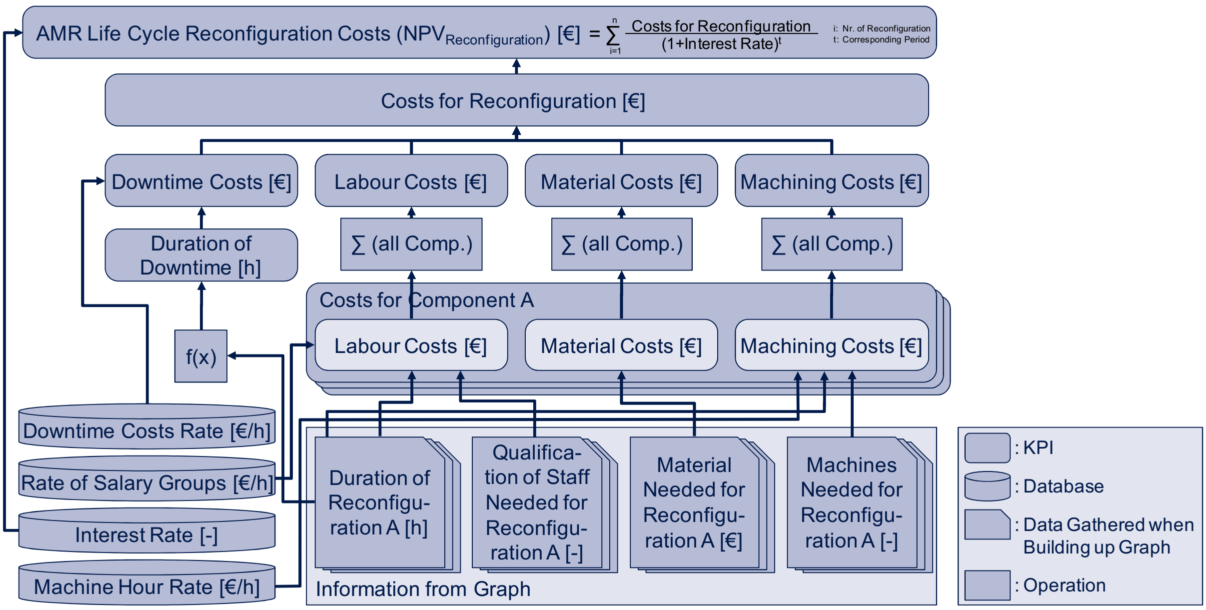

Figure 3. Economic KPI system

The economic KPIs can be used in various fields. Costs for reconfiguration can be used to compare different reconfiguration paths, since reconfigurations can be implemented in different ways by adapting varying components (e.g. possibility A and B in Figure 2). Thus, the most economic possibility can be chosen. Furthermore, this KPI can be used for estimating costs of a reconfiguration. These can be compared to the profits gained through the reconfiguration to rate profitability. Costs for component can be utilized in order to figure out whether it is more efficient to adapt or replace a component. Moreover, AMR life cycle reconfiguration costs are applied to compare two different characteristics of an AMR. Hence, additional invest in order to increase reconfigurability of an AMR can also be compared to the reduced reconfiguration costs. Finally, KPIs can also be fixed in specification sheets during announcements to specify requirements regarding reconfigurability.

5 EXAMPLE

In order to increase user friendliness of the methodology, a Microsoft Excel® based software tool was developed. It guides the user through the methodology and creates the graphs and KPIs automatically.

The program is an Excel add on and it was realized in Microsoft Visual Studio®. Graphs are visualized in Microsoft Visio®.

Biedermann et al. (2010) describe the AMR considered in this example. It is an AMR to assemble a toy. The assembly operation is executed by a robot and the ARM consists of 103 components that are connected to each other. The following scenario is analysed: doubling product size. Figure 4 shows the graph evoked by this reconfiguration. It was built up by the Excel tool based on the evaluation methodology (Figure 1). The node at the top is the initial event (doubled product size). In the nodes further information about the work to be carried out on the specific component can be found and the kind of impact is described (e. g. change or replace). On the edges the type of relation between components is shown (e. g. contact). The scenario results in following selected KPIs:

- Structural KPIs (number of adaptations: 13; number of connections: 10; depth: 6; snowball factor: 7 2/7; range: 12.6 %)
- Economic KPIs (costs of reconfiguration: 5.580 €; downtime costs: 3.500 €; labour costs: 960 €; material costs: 620 €; machining costs: 500 €)

When considering the structural KPIs it can be seen that the reconfiguration is not too complex since only 12.6 % of the components are affected. Due to the economic KPIs, it can be figured out whether it is economic to reconfigure the AMR or if it was more reasonable to invest in a new more reconfigurable AMR. Costs of Reconfiguration can for example be compared to additional income gathered in order to decide whether the invest pays or not. Hence, the KPIs and the KPI system presented in this paper give valuable information.

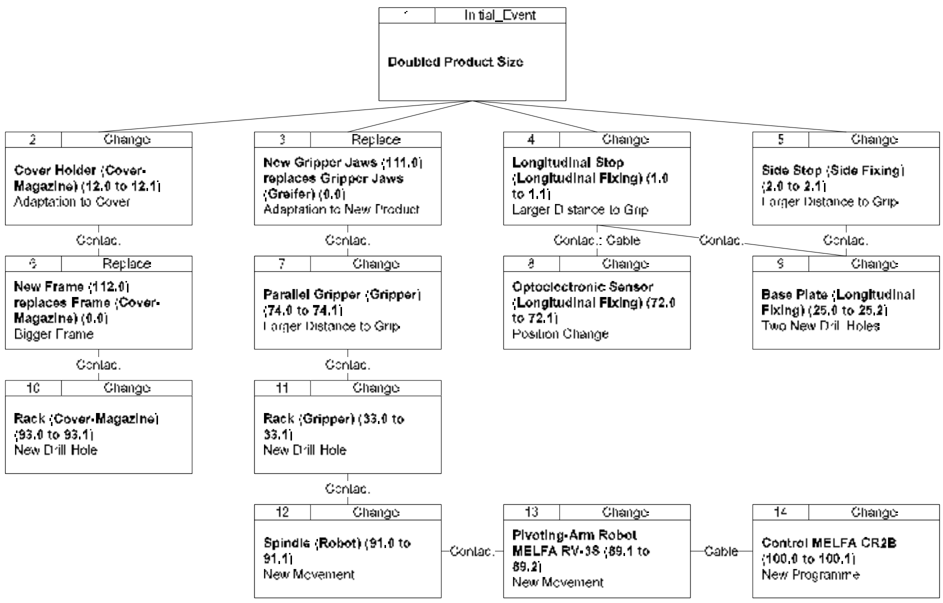

Figure 4. Example (effects of a doubled product size on an AMR)

6 SUMMARY AND OUTLOOK

In this paper, a DSM-based methodology for evaluating reconfigurability of assembly manufacturing resources (AMRs) was presented. Especially, KPIs for the evaluation were introduced, since common KPIs to evaluate DSMs are not directly applicable for AMRs. Two categories of KPIs were introduced: On the one hand structural KPIs were described. Since costs are crucial in evaluation and decision making processes, economic KPIs were illustrated on the other hand. Furthermore, an economic KPI system was presented. By using the evaluation methodology and the KPIs reconfigurability can be evaluated and requirements in specification sheets defined (e. g. in investment processes). Finally, an example explained the methodology and the KPIs. Future research work will focus on the industrial evaluation of the methodology.

ACKNOWLEDGEMENTS

This research was made possible through the generous funding by the German Research Foundation (DFG) in the context of the subproject B5 (“Design of changeable production resources”) and the subproject A2 (“Modelling and analysis of discipline-spanning structural criteria and their impacts on product development processes") within the Collaborative Research Centre SFB 768 ("Managing cycles in innovation processes").

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DSM-Based Evaluation of Assembly Manufacturing Resources

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INVEST ON VISUALIZATION

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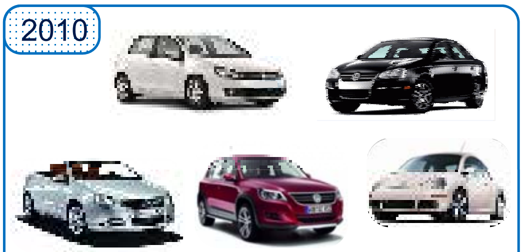
- Introduction
- Methodology to Evaluate Reconfigurability of Assembly Manufacturing Resources
- Key Performance Indicators (KPIs) to Evaluate Reconfigurability
- Application Area for KPIs
- Example
- Summary and Outlook

Introduction

1974

2010



… and even more

- Shortening product life cycles
- Rising number of product variants
- Assembly depends highly on changes in demand and variant diversity
- Influences on assembly of reconfigurations in upstream systems (e.g. production)

→ Number of necessary reconfigurations for assembly manufacturing resources (AMRs) rises

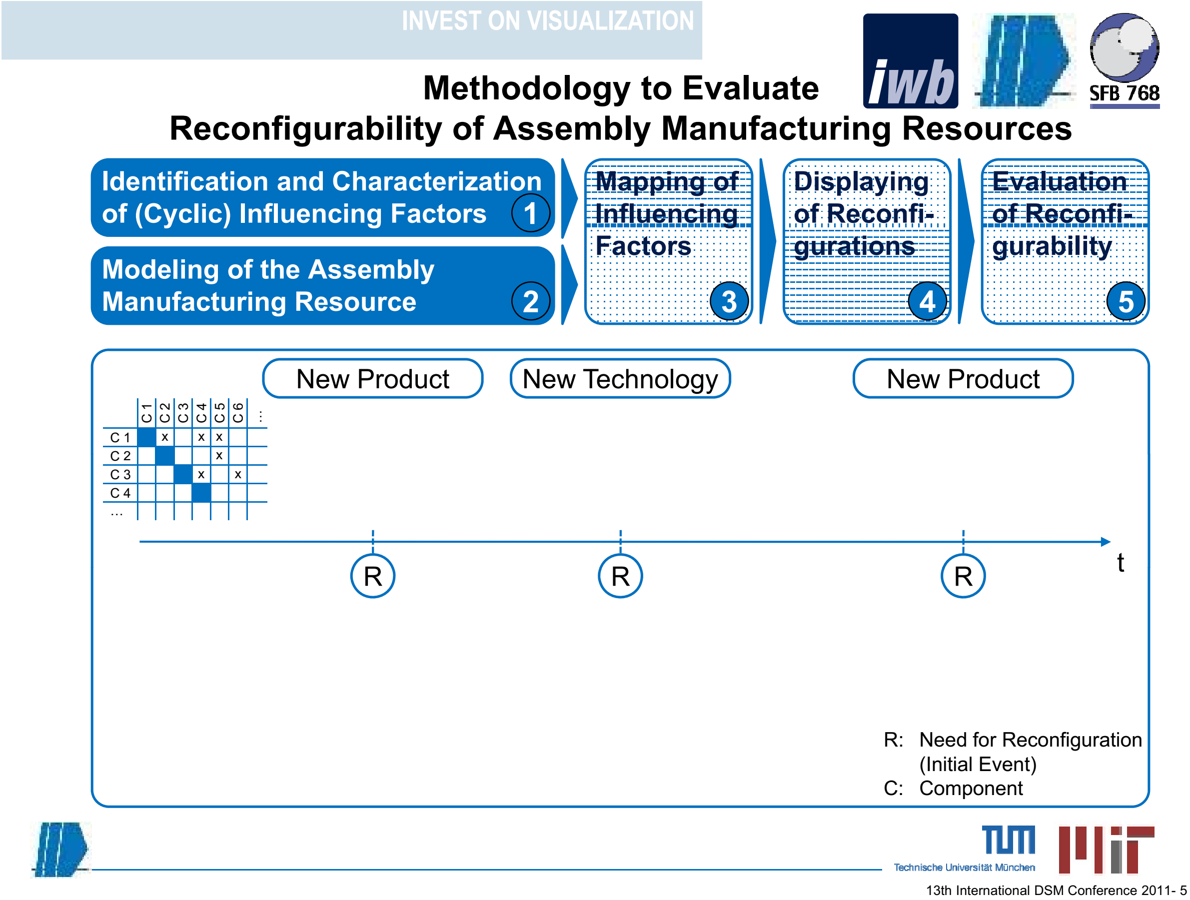
→ Growing need to evaluate reconfigurability of AMRs

Introduction

Research focus: Assembly cells executing at least one joining process

Structuring Levels of a Factory

- Network
- Site
- Segment
- System / line
- **Cell**
- Station
- Process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SFB 768
Methodology to Evaluate
Reconfigurability of Assembly Manufacturing Resources
Identification and Characterization of (Cyclic) Influencing Factors 1
Modeling of the Assembly Manufacturing Resource 2
Mapping of Influencing Factors 3
Displaying of Reconfi-gurations 4
Evaluation of Reconfi-gurability 5
New Product
New Technology
New Product
R
R
R
t
R: Need for Reconfiguration (Initial Event)
C: Component
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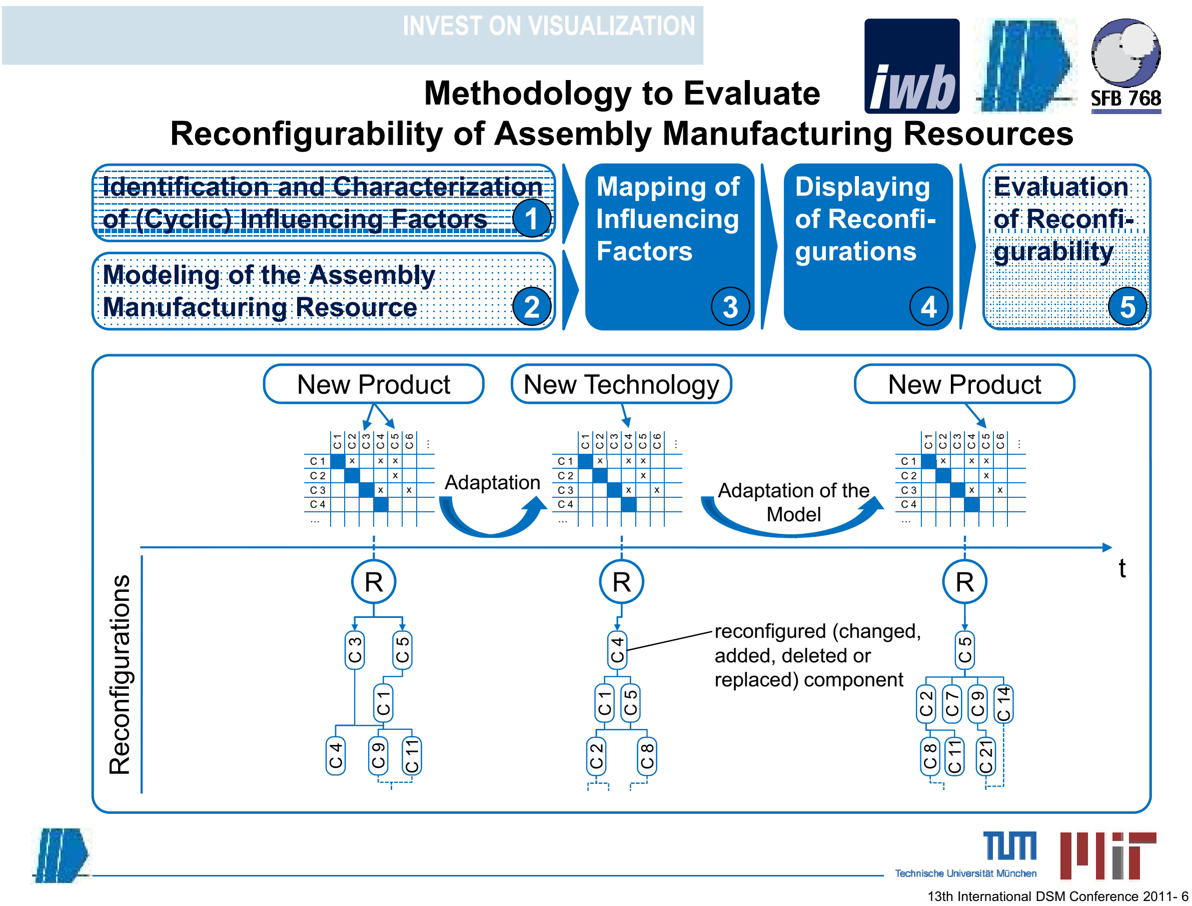
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Identification and Characterization of (Cyclic) Influencing Factors 1
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New Product
New Technology
New Product
Adaptation
Adaptation of the Model
t
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R
Reconfigurations
reconfigured (changed, added, deleted or replaced) component
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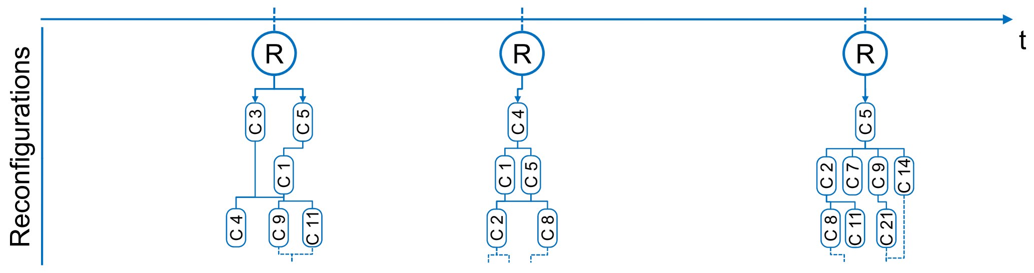
Methodology to Evaluate Reconfigurability of Assembly Manufacturing Resources

Identification and Characterization of (Cyclic) Influencing Factors 1
Modeling of the Assembly Manufacturing Resource 2
Mapping of Influencing Factors 3
Displaying of Reconfi-gurations 4
Evaluation of Reconfi-gurability 5

Need for graph-based key performance indicators (KPIs) to evaluate reconfigurability based on forecasted needs for reconfiguration:

- Structural KPIs
- Economic KPIs

Existing KPIs for DSMs cannot directly be applied as not all components are adapted.



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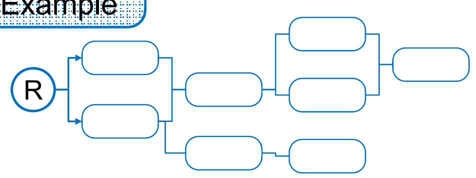
Key Performance Indicators to Evaluate Reconfigurability

Example



R: Need for Reconfiguration
Total Number of Components: 27

Number of adaptations:
8
Number of connections:
8
Depth:
4
Snowball factor:
4.25 (2/1+2/2+3/3+1/4)
Range:
29.63 % (8/27)

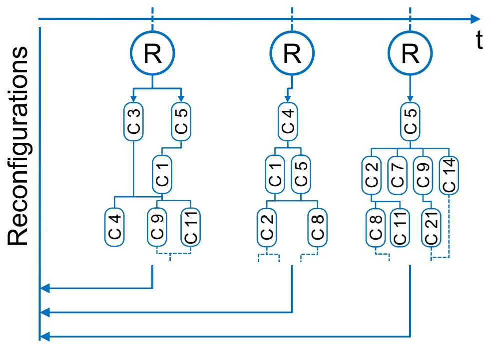
Structural KPIs for Evaluation

- Number of adaptations
- Number of connections
- Depth
  Length of longest branch in graph
- Snowball factor
  Sum over all adaptations of the reciprocal of the distance from the initial adaptation
- Scaled KPIs:
  – Range (number of adapted components / total number of components)
  – Density (number of connections / number of adaptations)
  – ...

References: Kreimeyer 2010,

Key Performance Indicators to Evaluate Reconfigurability

$NPV_{Reconfiguration}$



$$NPV_{Reconfiguration} = \sum_{i=1}^{n} \frac{c_{Recon.i}}{(1+r)^t}$$

$$c_{Recon.i} = c_{Labour.i} + c_{Material.i} + c_{Machining.i}$$

i: Nr. of Reconfiguration
r: Interest Rate
t: Corresponding Period
c: Costs

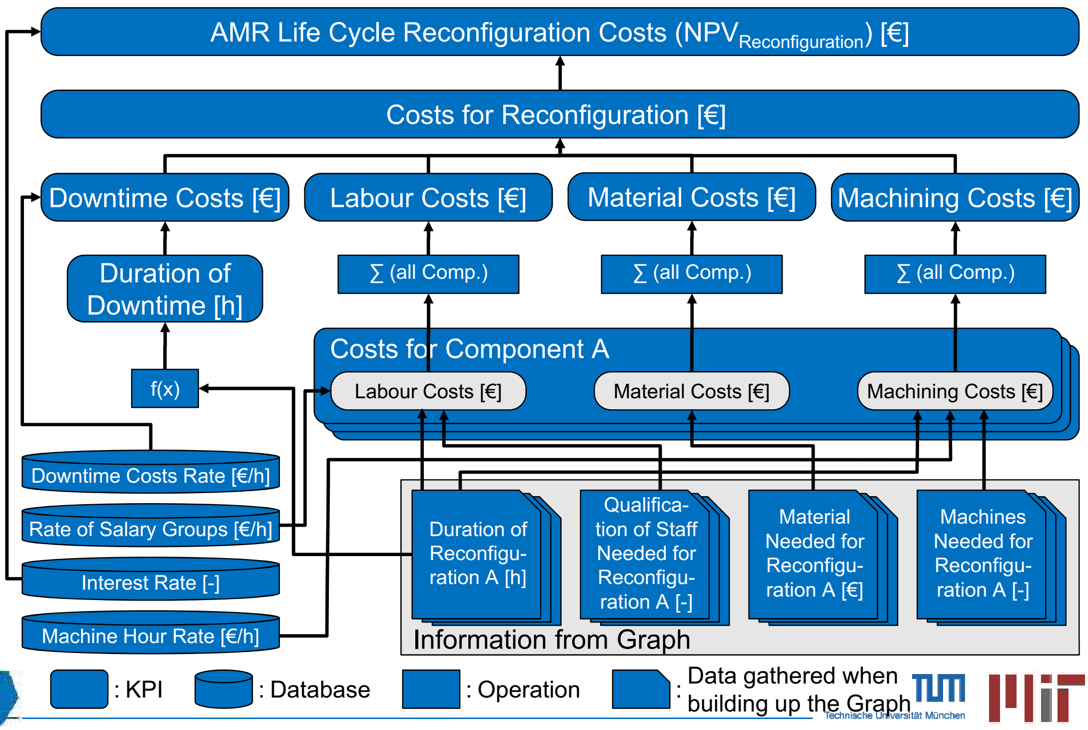
Economic KPIs for Evaluation

Chosen as they display various reconfiguration costs and times during an AMR life cycle at different levels:

- Reconfiguration costs per component
- Labour costs
- Material costs
- Machining costs
- Duration of downtime
- Downtime costs
- Costs for reconfiguration
- AMR life cycle reconfiguration costs ($NPV_{Reconfiguration}$)

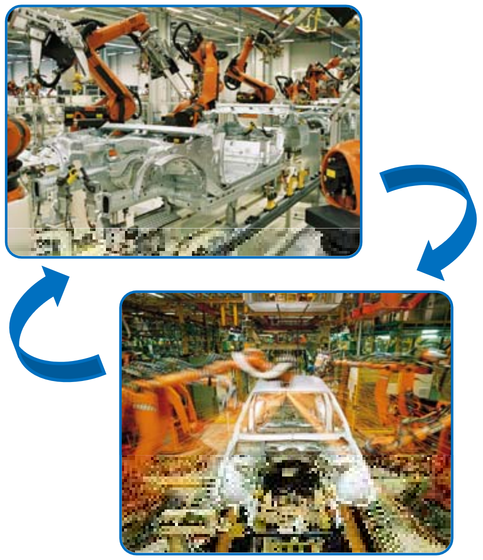
References: Zhang et al. 2006, Kerzner 2009, Redecker 1969, Zaeh et al. 2010

Key Performance Indicators to Evaluate Reconfigurability (Economic KPI-System)



Application Area for KPIs

Choice of AMRs

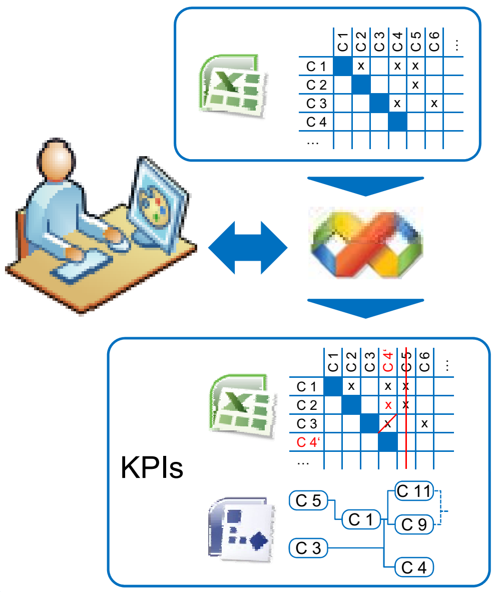


- Choice of AMRs in investment decision processes
- Determination of company-specific limits (e.g., in specification sheets during announcements)
- Economic analysis of additional investments for increasing reconfigurability
- Identification of innovation inhibiting components
- Comparing of different reconfigurations paths
- Estimation of reconfiguration costs
- ...

Pictures: BMW AG

Example

Software-Tool



Software-Tool to Support the User of the Methodology

- Input data
  - List of components
  - DSM for each kind of connection (contact, cable etc.)
- Software operation
  - Choice of KPIs
  - Request of data by user (e.g., reconfigurations evoked, costs for single reconfigurations)
- Output data
  - Reconfiguration graphs
  - KPIs
  - Adapted DSMs

Pictures: Microsoft Corporation

Example

Assembly Cell for Labyrinth Toys

AMR Considered
- Assembly cell for labyrinth toys
- Number of components: 103
- Evaluated scenario
  - Introduction of a new product
  - Adaptations evoked by doubled product size
- Considered DSMs:
  - Contacts
  - Cable

Pictures: Festo AG, Ben Strelkow, *iwb*

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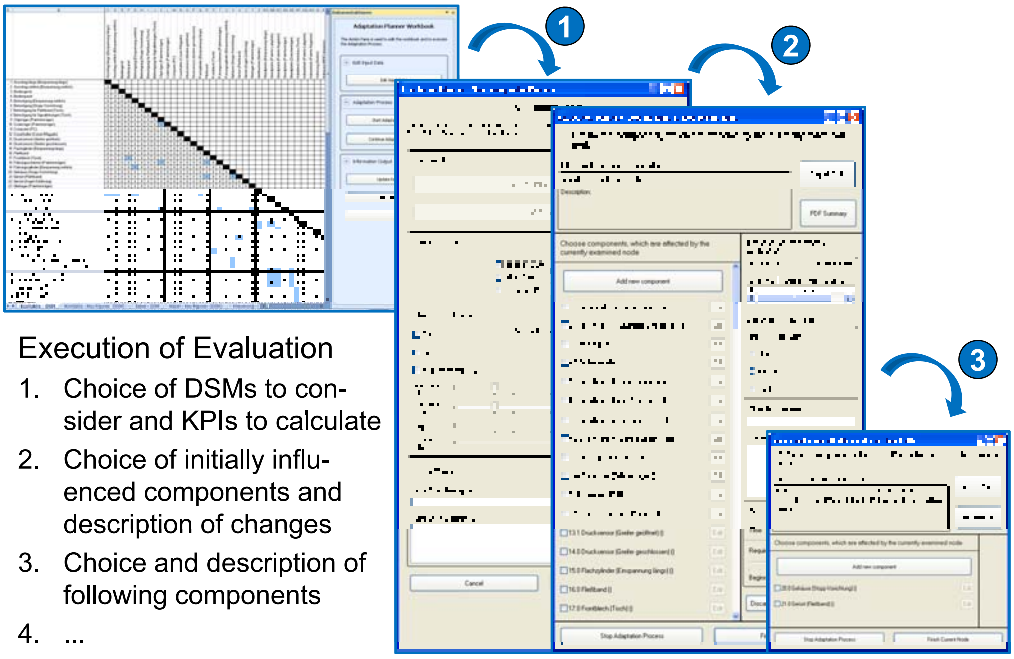
Example

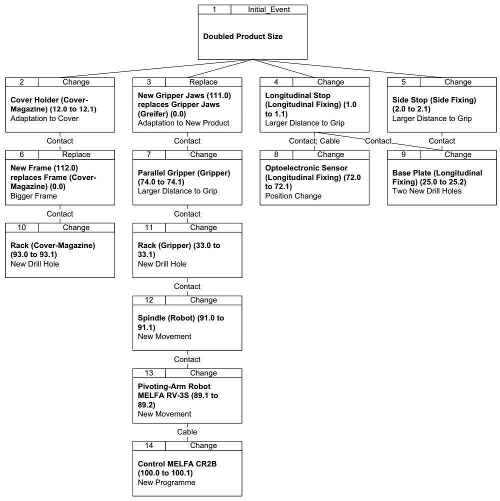


Execution of Evaluation
1. Choice of DSMs to consider and KPIs to calculate
2. Choice of initially influenced components and description of changes
3. Choice and description of following components
4. ...

Pictures: *iwb*

Example

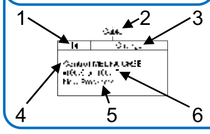
Reconfiguration Graph



Results of the Evaluation

- Structural KPIs
  - Number of adaptations: 13
  - Number of connections: 10
  - Depth: 6
  - Snowball factor: 7 2/7
  - Range: 12.6 %
- Economic KPIs
  - Costs of reconfiguration: 5.580 €
  - Downtime costs: 3.500 €
  - Labour costs: 960 €
  - Material costs: 620 €
  - Machining costs: 500 €

Description



1: Number of reconfiguration
2: Type of relation
3: Type of reconfiguration
4: Name of component
5: Description of reconfiguration
6: Number of component

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Summary and Outlook

- Summary
  - Rising number of reconfigurations on assembly manufacturing resources (AMRs)
  - Development of a methodology to evaluate reconfigurability of AMRs
  - Structural KPIs
  - Economic KPIs
  - Application exemplarity shown
- Outlook
  - Evaluation of correlations between KPIs
  - Integration of uncertainties in evaluation
  - Industrial evaluation of methodology and KPIs

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