Design of Manual Assembly Systems Focusing on Required Changeability

B. Baudzus, M. Krebs, J. Deuse
Institute of Production Systems, TU Dortmund University, Germany

Abstract
Due to fast moving markets in times of globalization, manufacturing companies are nowadays faced with less predictable trends like high fluctuations in sales volume or increasing product variety. As a reaction, companies implement changeable production systems as a strategic objective. The outstanding factor is the ability to adjust the system even outside of provided corridors of flexibility in a short period of time and with low investments. This paper deals with the process of designing a manual assembly system target-oriented to specific potential changes. For this reason, a method is shown which offers dynamic rankings of system elements. These elements have to be designed to support weighted system characteristics which are necessary to meet a potential change in a selected dimension. In this way a company is able to enhance its changeability to benefit from its advantages.

Keywords
Changeability, Manual Assembly System, Design

1 INTRODUCTION

Being part of global markets, the producing industry is faced with highly dynamic environments [1]. These environments cause disturbances which lead to unpredictable fluctuations of relevant economical dimensions. Concerning the production system these dimensions of change include quantity, quality, time, product and costs and can be described by a large amount of internal and external factors which are called drivers of change [2]. Those can be clustered into the fields of competition, technology, general legal framework, customer and market requirements, suppliers, staff and others [3].

To meet the impact, companies have to be capable to adjust their production and assembly systems time and cost efficiently in case of an occurring change. Provided corridors of flexibility are not able to carry those changes anymore, because they are limited to a defined extend [4]. For this reason companies invest in changeable production systems as a strategic objective [5]. Applying this approach means to design the whole production system in the areas of technology, logistics, human resources and organization according to specific requirements. It would however not be cost efficient to design systems with a maximum of changeability, as doing so would result in large losses in the absence of a change.

Thus, this paper deals with the process of designing a manual assembly system target-oriented to a specific potential change. It presents a method for identification of change enabling characteristics and leads to technical solutions.

2 CHANGEABLITY OF PRODUCTION SYSTEMS

2.1 Production systems

A production system is a socio-technical system, which transforms input (e.g. material) during value adding (e.g. assembly) or supporting (e.g. transport) processes into output (e.g. products, waste)[6]. It consists of several system levels which can be described hierarchically from the network via the factory to the workstation [6]. The target of a production system is to create products of higher complexity in a sequence of processes [7].

2.2 Manual assembly systems

The asssembly is a subsystem of the production system and includes all resources to complete the assembly tasks [8]. Depending on the level of automation, the assembly can be divided into manual, automated and hybrid systems; the hybrid assembly system decribes a combination of manual and automated assembly [6].

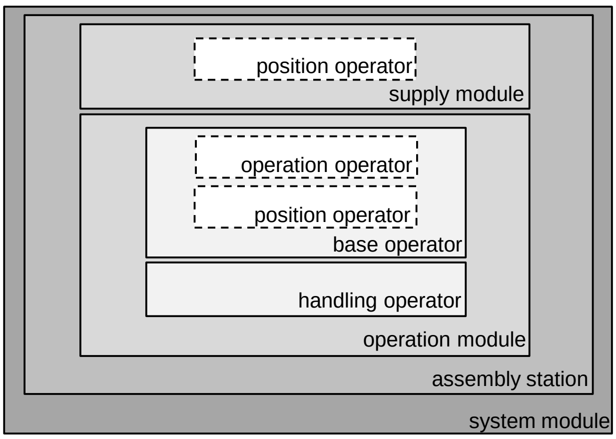


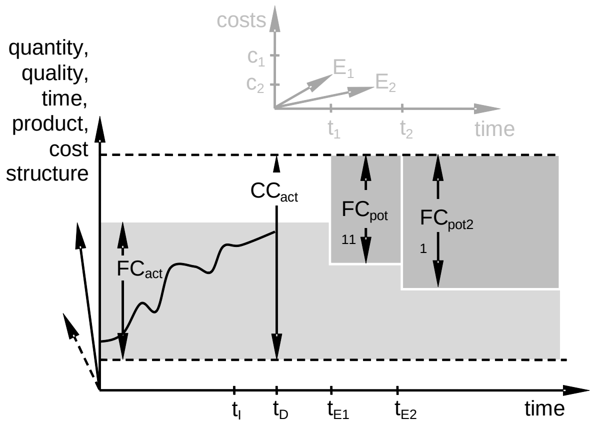
Figure 1 - System module [9].

This paper focuses on the manual assembly because it is still a widespread concept in the production of products of higher variety in the German industry.

In the context of this paper an assembly system is described as a system module (Figure 1)[9]. The module includes information about the layout and the linking principle (i.e. assembly line) of assembly stations. The assembly station consists of the operation module (operational part of an assembly station) and the supply module (element of material supply). The operational module covers the handling operator (handling processes, i.e. conveyor belt) and the base operator. The base operator provides the basis for the assembly (i.e. table) and is divided into the position operator (ensuring a defined place for the workpiece or material, i.e. fixture) and the operation operator which basically performs the assembly (i.e. tools).

2.3 Flexibility and changeability in a production system

Each assembly system has a defined flexibility corridor. Flexibility enables a production system to adjust to new requirements in a limited corridor quickly and with minimum investments [3,4]. Leaving the definded corridors in one or more of the dimensions of change (quantity, quality, time, product, costs) is connected with indefinite expenses and a loss of time in the market competition. Due to this reason changeability becomes a relevant approach. There are various interpretations of changeability [2,5,10-12], and in this paper it is defined as the potential of a production system to carry out technical, logistical, human or organizational changes outside of provided corridors in a short time and with low investment in the change dimensions [13].



FC_{act}: Actual flexibility corridor
CC_{act}: Actual changeability corridor
FC_{pot}: Potential flexibility corridor
t_I: Identification of need for changeability
t_D: Decision about measures for the change
t_E: Effect of a measure
c: Costs
E: Activation effort

Figure 2 - Systemic changeability [13].

It is of particular significance to align flexibility and changeability. The relation between these two approaches is shown in Figure 2. Since the spanning of a changeability corridor is linked with costs, it is important to cover only the presumable trends in the change dimensions [6, 14]. The maximum degree of changeability does not necessarily meet the optimum [15].

2.4 Changeability enablers

To attain changeability in the designing process of an assembly system, enabling system characteristics have to be developed to support a transformation in case of a change [16]. In this context five characteristics are specified: universality, scalability, modularity, mobility and compatibility [11,17]. Universality describes the ability of an object to be designed and dimensioned for differrent demands. Scalability represents extensibility in the areas of technology, layout and personnel. Modularity of units ensures interchangeability of system elements with little cost or effort. Mobility provides required dislocation of objects. Compatibility is based on standardized interfaces to guarantee varius interactions between objects [11]. To generate one or more of those enablers, the specification of elements of manual assembly systems have to be chosen accordingly.

As the changeability enablers are quite generic, characteristics have been identified to describe the enablers more precisely [18]. These characteristics help to get ideas related to requirements for construction elements with an influence on the neccesary system properties. Mobility can for instance be further subdivided into degree of connection, weight, transportability, carrying capability, (dis-)assembly, sensitivity of transport and dimensions. Altogether, the five change enablers have been detailed in 37 characteristics [18].

3 DESIGN METHODOLOGY

3.1 Target and course of action

If a company presumes a possible change, it is a strategic objective to invest in changeability. From the moment of the completed planning process onwards, the system becomes changeable. If a change occurs, the planned system with its flexibility corridor with defined limits can be activated. If the change fails to appear, the investment in the planning process is superfluous. Thus, it is necessary to make this planning and designing process as efficient as possible to minimize the costs. For this reason the goal of the presented methodology is to support designers in the development process of changeable assembly systems. Therefore it is necessary to get information for potential and required design solutions as fast as possible. Figure 3 shows the different steps of the method.

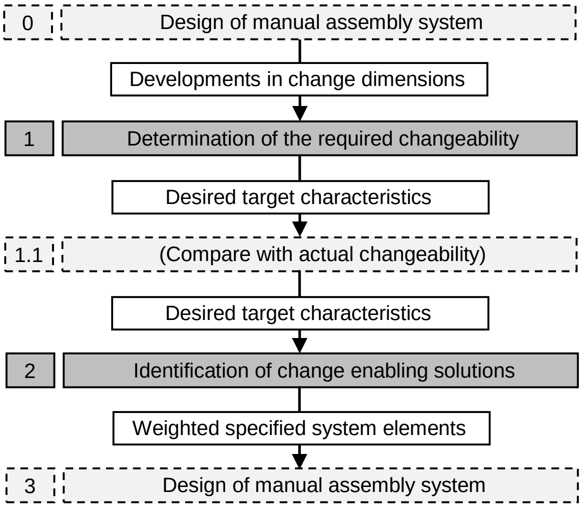


Figure 3 - Course of action.

After an analysis of the change drivers and the developments in the change dimensions (step 0), the required changeability has to be determined (step 1). To meet a potential change in a selected dimension exactly, it is necessary to analyse, which characteristics support a change in this dimension. The methodology is basically universally valid, so if an existing system is supposed to be used further on, a comparison between the target and the actual characteristics can be integrated (step 1.1). As a second step, change enabling solutions have to be identified. Thus, it has to be evaluated which specifications of system elements can realize the required properties. The result is a register of weighted specified system elements which illustrates the restrictions for the designing process (step 3).

Beside the previous research [3,18], steps 1 and 2 have been identified as necessary steps of the designing process to precisely meet the requirements. Thus this paper focuses on the steps 1 and 2. Step 0 is described completely in [3], the evaluation of actual changeability of assembly systems (step1.1) in [18]. Step 3 is an individual process in every company. It is described in more detail in Chapter 4.

3.2 Evaluation of required changeablity

Step 1 includes the determination of the required changeablility. The input is the specification of the dimensions of change and the output is supposed to be the desired target characteristics of the system. Hence these two criteria have to be connected. A simple tool is used to connect the two variables on the basis of equation 1.

$$R_i(P_D) = [\sum_D P_D \cdot M_{DC_i}] \cdot W_{C_i} \qquad (1)$$

This equation describes the ranking value R for the i^{th} characteristic of the system. This applies if the dimension D is assumed to be D = {quantity, quality, time, product, costs} with the related variable probability of the occurence of a change in the specific dimension $P_D = \{P_v, P_q, P_t, P_p, P_c\}$ and is 0 or 1. P_D is generated during the analysis of the change drivers. M_{DC} is the value of the degree of connection between the variables. If the characteristic is able to support a change in the specific dimension it is given one of the values 0,1 or 3. If the value is 3, it is connected. The value 1 describes a loose connection and 0 no connection. W_C is the weighting between the characteristics regarding their importance amongst one another [18]. Their sum is equal to 1 in each of the five fields. Figure 4 shows a detail of the tool.

characteristics \ dimensions of change		P_d / W_c	quantity	quality	time	product	cost	
			P_v	P_q	P_t	P_p	P_c	R_i
Universality	restriction (ecolog.)	0,11	1	0	0	1	1	
	techn. idp.	0,21	1	0	1	3	3	
	variants/product idp.	0,25	1	0	1	3	3	
	sensitivity	0,04	0	1	0	1	1	
	degree of automation	0,11	3	3	3	1	3	
	precedence of w ork content	0,11	1	3	1	1	3	
	customer decoupling	0,18	0	0	0	1	3	

Figure 4 - Used tool in step 1.

Using this equation, the result is a ranking of all sytem characteristics which enable the system to the considered change in one or more dimensions.

3.3 Evaluation of system element designs

In step 2 the characteristics mentioned above have to be combined with solutions for the system elements and the connected organizational functions.

For this reason, all the elements of an assembly system which can be designed (e.g. table, tools, fixtures, interfaces) have been collected and assigned to the modules and operators of the system module (Figure 1) in a first step. Afterwards solutions for the design of the elements have been added (e.g. hinge-joints, magnets, clamps, bolted or welded joints for interfaces). In many cases there is more than one solution for the design.

Each solution is supporting one or more change enablers as well as the more specific system characteristics (e.g. transportability). Additionally, each of the specifications of the solution have a distinct effect on the degree of changeability. Thus, in preparation each solution has been rated for its capability to support a defined characteristic [18].

Using the methodology, the input for the tool is R_i (Equation 1). As a function of R_i the result for the impact of the solutions I_j on the neccesary characteristics is demonstrated by Equation 2.

$$I_j(R_i) = [\sum_{C} N_{SjCi} \cdot R_i] \cdot F_{Sj} \quad (2)$$

N_{SjCi} is the matrix item which combines the characteristic with the design solution. The factor is a further development of an existing evaluation model [18]. F_{Sj} is a factor which is determined by the company and sets the boundary constraints. If e.g. the operation module is not supposed to be mobile F_{Sj} is rated 0 and the corresponding design solutions are not taken into consideration. Otherwise the factor is set to 1. In Figure 5 a detail of the tool is shown.

The result is a register of possible changeable solutions. The solutions are named and I_j is added as the impact of the solution for changeability. Out of this explicitly developed register for a certain change profile, the designer chooses the combination which matches precisely with the company's needs to find a balance between changeability and incuring investments.

4 CASE STUDY

4.1 Company and product

The example of use applies to a medium-sized German company which produces high-tech precision mechanical equipment in single- and small series production. The product of the examined workplace causes special demands regarding the precision of the assembly. Thus the workstation is supposed to have a seated work position and has to be fixable to the ground. Another constraint is the high number of very small parts and a large number of tools. The assembly can be divided and balanced evenly by lot sizes into 5 subassemblies, 3 group assemblies and a final assembly.

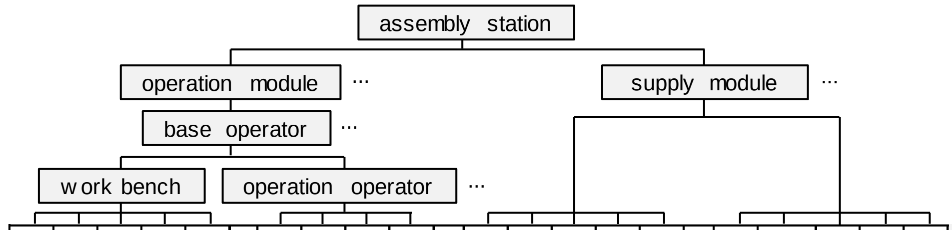
4.2 Predicted change

The predicted changes affect the change dimensions sales volume (probability 90%) and product variety (probability 30%). Current figures show that sales volume could cross the actual upper capacity limit in the near future. However, it is uncertain whether the high sales volume will last over the whole product life cycle. Another possible change concerns the product variety. Due to technical improvements the existing product could be replaced or varied in the near future. Additionally, the product is going to be delivered to the Asian continent where different technical standards affect the product structure.

4.3 Result

The company attaches importance to enable the system for the above mentioned possible changes and to increase changeablility. For this reason the methodology is used to identify change-supporting system characteristics which can be activated in case of a change.

The result of the determination of the required changeability is a ranking of charactersitics of each change enabler. The highest rated characteristic (R_i=0,7) concerns the realisation of a capacity corridor (scalability) followed by variants/product independance, (R_i=0,6) (universality), ability of



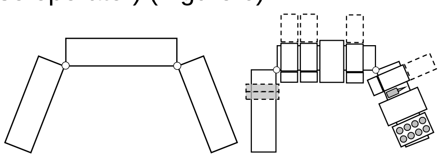
		no connection	force fit	form fit	material connection	foundation	…	specialized process	conventional process	multifunctional process	manual process	…	no connection	force fit	form fit	material connection	foundation	…	not transportable	transportation conditioned by load and shape	standard transport	simple transport (hand cart)	integrated transport (rolls)	…
characteristic	R_i \ F_{Sj}	0	0	1	1	1	…	0	0	0	1	…	1	1	1	0	0	…	0	0	1	1	1	…
capacity corridor	0,70	2	1,5	1	0,5	0	…	0	0	0	0		2	1,5	1	0,5	0	…	0	0,5	1	1,5	2	…
variants/product idp.	0,60	2	1,5	1	0,5	0	…	0	4	7	10	…	2	1,5	1	0,5	0	…	0	0,5	1	1,5	2	…
ability of exchange	0,60	2	1,5	1	0,5	0	…	0	0,7	1,3	2	…	2	1,5	1	0,5	0	…	0	0,5	1	1,5	2	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	…
degree of connection	0,30	10	7,5	5	2,5	0	…	0	0	0	0	…	10	7,5	5	2,5	0	…	0	0	0	0	0	…
transportability	0,30	2	1,5	1	0,5	0	…	0	1	1,3	2	…	2	1,5	1	0,5	0	…	0	2,5	5	7,5	10	…
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
	I_j	6,5	5	3,4	1,9	0,3	…	3,6	6,7	9,9	13	…	6,5	5	3,4	1,9	0,3	…	0	1,3	2,6	3,9	5,2	…

Figure 5 - Used tool in step 2.

exchange (R_i=0,6) and standardized interfaces (R_i=0,3) (modularity) and the specification of the degree of connection (R_i=0,3) and transportability (R_i=0,3) (mobility).

Regarding the constraints (fixed work bench) the focus in step 2 lies on the supply module. In Figure 5 a cutout of the result of the evaluation is shown. Based on the values for I_j, the recommended design solutions are e.g. no connection to the ground (I_j=6,5) or a force fit (I_j=5) and a simple (I_j=3,9) or integrated transport concept (rolls) (I_j=5,2). Furthermore, a very universal design (I_j=13) with standardized interfaces (I_j=6,1) is proposed for the work bench. To ensure scalability, it should be possible to integrate additional modules. This also affects the balancing capability.

Taking these ideas for design solutions regarding changeability into considerarion, the assembly system is designed with the German supplier LP Montagetechnik GmbH. Based on that, the finished solution includes fully moveable supply modules which can be arranged around a fixed work bench (base operator) (Figure 6).



(a) (b)

Figure 6 - Movable supply modules (top view).

The modules can be equipped with the necessary parts and tools for the assemblies and offer the flexibility to adjust the system easily to new parts and products. The parts for the modules and the subassemblies are stored in a supermarket system near the workplace. The modules include swivelling holders so that the part can be brought as near to the assembly position as possible to ensure an efficient and ergonomic process.

Figure 7 shows supply modules arranged around the fixed work bench. There are additional modules for bigger parts.

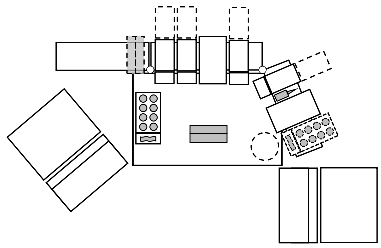


Figure 7 - Supply modules arranged around fixed work bench.

Besides the technical solutions the methodology offers some organizational solutions as well. These recommendations are strongly connected to the designed systems, so they need to be adjusted together with the responsible planner of the company.

Implementing this system, the company immediately enhances its flexibility and changeability corridors. The flexibility for the assembly of other products of a similar spectrum increases by using the supply modules which can be equipped flexibily. Additonally, the solution offers changeability regarding the sales volume in terms of scalability. If the sales volume is low, the system can be reduced to one fixed work bench. If the sales volume rises, additional fixed work benches can be installed to realize a batch assembly.

5 CONCLUSIONS

In the paper a methodology is presented to support designers of assembly systems in the process of creating a changeable solution. In doing so, it is necessary to cover only the presumable trends in the change dimensions to hold investments at a minimum level. As seen in the case study, the presented methodology allows the design of a changeable manual assembly system aligned to the defined needs.

The main advantage using the method at the beginning of a design process is the early consideration of changeable solutions for a specific change. Of course, it doesn't replace the creative process, it helps finding basic ideas though.

Future developments could concern the connection of the method to an in-plant database with already designed solutions for elements of the assembly system. Thus, the process to enhance changeability could be further simplified and shortened.

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8 BIOGRAPHY

Barbara Baudzus obtained her Dipl.-Ing. in Mechanical Engineering from the TU Dortmund University. Currently she is working at the Institute of Production Systems at the TU Dortmund University, Germany in the field of assembly systems design.

Matthias Krebs holds a Dipl.-Ing. degree in Mechanical Engineering from the TU Dortmund University. He is currently working as a research engineer at the Institute of Production Systems at TU Dortmund University, Germany. His work scope includes Time Data Management, Work-System-Design and Technical Cleanliness.

Jochen Deuse obtained his Dr.-Ing. degree in Mechanical Engineering from RWTH Aachen. In 2005 he was appointed Professor of Production Systems and Industrial Engineering at TU Dortmund University, Germany. Before entering TU Dortmund he had various management assignments within the Bosch Group.