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# ASSESSMENT OF THE CHANGEABILITY OF PLASTICS PROCESSING SYSTEMS

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## Abstract

Changeable production systems are still being developed, especially in the field of plastics processing. Here, the assessment of the changeability is a decisive factor. This investigation deals with the assessment of the changeability of a modular pilot plant, and derives approaches for the further development of an evaluation system, as well as potential means to increase the changeability.

## Introduction

The production systems of tomorrow are subject to a continuous advancement of their complexity. An increasing degree of automation, more precisely specified product properties and an enhanced integration of processes in one another, are only a few developments which contribute to this. Simultaneously, a stronger individualization of products leads to a higher number of variations. Sales volumes, which are more difficult to predict, demand a higher variability of the quantity and decreasing production batches. Just as is the case for the product life cycles, which continue to shorten, these developments demand that production systems possess a high adaptability. The arising conflict demands, on the one hand, that production systems be highly specialized and ideally tailored for application, and, on the other hand, highly flexible and variable. It is especially present in high-wage countries.

Owing to its numerous process variants, the plastics processing industry has also been targeted by this problem. The changeable design of production systems represents an approach to solving this problem. The assessment of the changeability is a significant aspect in regards of continuing research of an application of this concept in a real production setting. An objective measurement of the changeability is the basis needed to determine flaws and resulting needs for action or research. It is also the fundament for a comparison of manufacturing systems in the context of investment decisions.

This investigation aims to show to which extent existing methods can be employed to assess the plastics processing environment. By means of an exemplary realization of an evaluation, not only the needs for action for the improvement of the assessment system shall be shown, but also the development potential for the design of plastics processing systems. A modular pilot plant developed at the Institute of Materials Engineering of the University of Kassel will be used for the assessment. [1]

## Changeable Production Systems

Numerous concepts exist which attempt to specify the idea of adaptability more precisely in its entirety, or aspects of it. The broadest definition is that of the term agility. It describes the ability of a company or network of companies to proactively develop new structures [2].The aspect of acting of one's own accord is a component of the definition of changeability. In contrast to agility, this term only refers to the factory level, which excludes strategic company functions such as sales [3]. The most important criterion for changeability is that technical or organizational alterations can still be carried out beyond flexibility corridors planned in advance [4], and are not subject to explicit limitations [5]. Contrary to flexibility, an additional temporal or financial effort based on the alteration arises at the actual point in time when the alteration is realized [6]. At the same time, changeability encompasses flexibility, and expands the concept with the aspect of reactivity [7], or the ability to respond [8].

## Description of the Object of Assessment

The system to be assessed is a pilot plant for researching changeability in plastics processing, and is installed at the Institute of Materials Engineering. As Figure 1 shows, the system consists of a vertical, hydraulic injection molding machine and a friction welding machine, which are linked to one another by a six axis robot.

Figure 1: Changeable pilot plant.

Separate from another, the injection and clamping units are each equipped with individual hydraulic circuits. A semi-automated tool change can be completed on roller conveyers. The variation of the underside of the tool alone enables the production of three variants of one product. It is a hexagonal cube with an inner section, which can be filled by a second injection unit. Alternatively, it is also possible to produce hybrid components by inserting aluminum tubes. The welding heads of the welding machine can be changed by the robot. Thus, other welding processes can be employed apart from the currently installed circular welding.

The system is coordinated via a central control which directs the processes initiated by a software for process and order generation to the individual controls of the module in combination with the according parameters. After the completion of the processes, the same system records the response, and returns it to the software. It is possible to combine single process steps to entire processes by creating work plans with the software. A job manager is available for the administration of the production orders.

## Assessment of the Changeability

The goal cannot be to achieve a maximum degree of changeability [8]. Instead, the necessary degree of changeability for a company, or even for a singular production system results as the optimum of predicted need for change and technically-economically realizable solutions.

Essentially, various approaches for the evaluation of changeability exist. Depending upon the application purpose of the method, they are employed with differing intentions. For instance, from a technical perspective, an assessment can be carried out to determine the changeability value. This enables a comparison of various technical systems in regards of their changeability. Such a comparison can be employed as the decision criterion when deciding between otherwise identical alternative production systems.

The additional determination of a targeted level of change makes it possible to make a statement as to how far the system fulfils the same. Such a target/actual-comparison often forms the basis for an optimization procedure, which equalizes changeability deficits by altering existing, or selecting new system components. Besides a purely technical perspective, an assessment also finds justification in monetary viewpoints. According values are employed comparatively for the selection of investment options, and for the general inspection of the economic efficiency. Often times, the prerequisite for an economical assessment is a technical observation.

Existing methods were observed on various factory levels depending on the application purpose. The authors of the singular methods use various definitions of factory levels. For comparability purposes, the classification in Figure 2 is based on the factory levels used by Bredow [9].

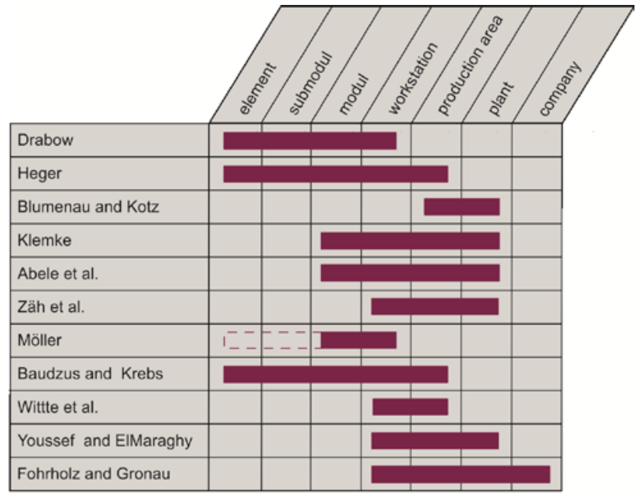


Figure 2: Different assessment methods with considered factory levels. [10-21]

The levels element, submodule, module and workstation are relevant for the evaluation of a single production system like the modular pilot plant. The methods of Drabow, Heger and Baudzus and Krebs are possible approaches for the assessment. The approach by Möller was omitted, because he does not describe his own procedure for the first two levels. Instead, he refers to the methods of the other authors.

Many of these assessment methods use the concept of change enablers, or change receptors as a starting point. Change enablers are properties which enable the systems to adjust to changes better [22]. Change receptors are channels through which change effects production systems. Figure 3 shows which are taken into account by the according methods. The observed change receptors are borrowed from the study by Cisek [5].

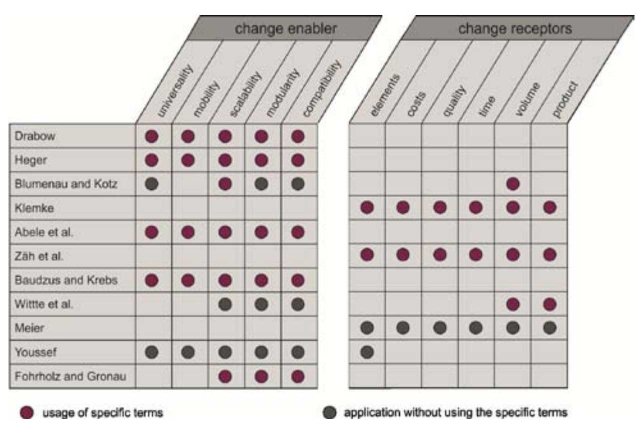


Figure 3: Use of change enablers and change receptors as basis for the assessment in various methods. [10-21]

The approaches of Drabow, Heger and Baudzus and Krebs include all five change enabler in their evaluations. Thus, the assessment can be described as holistic in all cases. Owing to the fact that the method by Drabow provided the most detailed description, it will be used as the basis for the assessment of the pilot plant [10].

## Description of the Assessment and Necessary Adjustments

Drabow bases his procedure on the change enablers. He assigns sub-criteria to each of the five Change enablers. They aim to describe the degree of realization of the enabler as objectively as possible. Every Sub-criteria is rated on a scale ranging from zero to ten. The Sub-criteria are weighted, and combined to an assessment for the according change enablers. Finally, a changeability index can be established for the production system, and consists of the weighted evaluations of the change enablers. [10]

Drabow developed his procedure for application in the field of machine tools. Consequently, a suitability of all criteria cannot be generally assumed for the plastics processing sector [11]. Subsequently, the assessment of the single Change enablers is illustrated shortly, including the necessary changes made to the procedure.

### Modularity

Assessment criteria describe the functional and physical independence of components and standardization of interfaces. When evaluating plastics processing procedures, the fact that components of the system, which can be physically separated and which have their own individual function (functional independence), are not readily exchangeable due to thermal dependencies must be taken into account. For example, demolding mechanisms in an injection molding tool are functional, and, according to the design, are physically separable. An exchange is still not possible in each case, because of a possible alteration of the heat dissipation.

Even the standardization of interfaces cannot necessarily enable the integration of new elements without problems. For instance, the integration of an additional injection unit (ancillary injection unit) into an injection molding process is often possible via a interface similar to the Euromap handling interface. However, the integration into the entire process course of injection molding is only possible at certain points in the injection molding cycle. Especially complex, integrated processes cannot be adapted despite standardized interfaces.

### Mobility

In order to assess the mobility, the source method uses the weight and the dimensions in the three space dimensions of the components as criteria. Also, the effort which correlates with the restructuring plays a role. These criteria can also be employed for machines and systems in plastics processing, because the assessment of the time and qualification needed to restructure the system include numerous aspects, such as the moveability or the necessary assembly effort.

### Universality

One criterion for evaluating the universality is the coverage of production processes. It represents the ratio of the number of already installed processes in relation to the number of current processes as well as those which will be needed in the future. For this purpose, a clear definition as to which processes generally exist is needed, in order to identify those already covered, and to find those needed in the future.

In regards of the investigation of potential processes, Drabow refers to DIN 8580 [23]. The classification used there is not precise enough for plastics processing with its numerous differing and special procedures. Therefore, an alternative procedure arrangement was used for the classification. The welding principles of DIN 1910/3 were used to define potential welding processes [24]. Potential handling processes were taken VDI standard 2860 [25].

It is difficult to determine a basic method portfolio for injection molding, because no uniform definition exists. According to this single-component injection molding, two-component injection molding, hybrid injection molding, injection molding using the fluid injection technique, foam injection molding and injection molding which uses special tool technologies, i.e., rotary table molds and cube molds, were selected as potential methods. Similar definitions must be added for further plastics processing methods, such as extrusion, in order to complete the methodology.

### Compatibility

This criterion examines the interfaces between the assessment object and its environment. Mechanical requirements, required floor space, or necessary medium or supply line play a role. Also, various emissions are regarded and assessed.

The only adjustment needed was an expansion of the observations of the emissions in regards of outgases, so as to be able to take additional expenditures for suction devices and similar equipment into account.

### Scalability

In the context of scalability, the system's handling of quantity changes is observed. Apart from the ability to lower or increase the output, the reusability of exchanged resources is relevant in this context. These criteria were adapted, because of their application independence.

## Assessment of the Pilot Plant

The total evaluation of the changeable pilot plant resulted in a score of 6.7 points (on a scale ranging from 0 to 10, 10 being the highest possible score). The individual evaluations of the change enablers are shown in Figure 4.

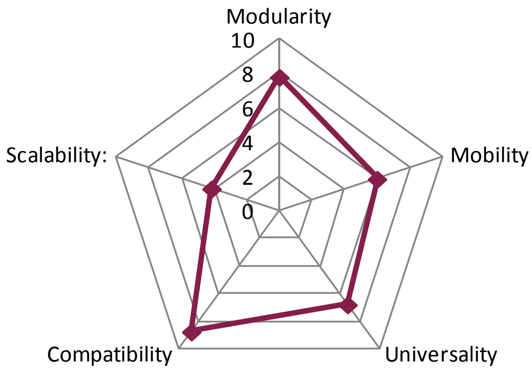


Figure 4: Evaluation of the change enablers.

The modularity and compatibility are especially pronounced in the pilot plant. This reflects the targeted separation of functions, and the creation of standardized interfaces in the system. The scalability was least pronounced of all. This shows that this is where the largest need for development is. In principle, a distinction can be made between scaling by means of adapting a system resource and scaling by means of adding or removing resources. The former is particularly difficult to realize due to the procedures employed in the system (injection molding and vibration welding). A significant increase of the quantity can only be achieved in both cases by increasing the number of cavities in the tool. Here, the necessary forces (clamping force, welding pressure) and clamping surfaces must be available. Due to the fact that a general overdimensioning does not comply with the changeability approach, and, additionally, is not useful from an economic perspective, other means must be found. In the case of injection molding machines, it is possible to consider integrating standardized, small clamping units equipped with separate drives into an existing control system, in order to enhance the clamping force and clamping surface. Such a concept would also require accordingly variable tool concepts, as well as modular cooling and demolding concepts. The application of a multi-cavity mold is only possible in special cases for the observed vibration welding machine. Here, the largest potential lies in the reduction of both the handling and non-productive time, because they are high in comparison to the vibration and cooling periods. It is also possible to consider the usage of already loaded workpiece carriers, which are only coupled with the welding head during welding. All in all, the conceptualization of such systems for a broad field of application represents an area that still requires research.

## Challenges of the Assessment

During the analysis and the actual assessment, it became clear that there is still development potential in terms of the assessment methodology. The approach selected by Drabow has a modular structure, which enables the separate evaluation of single elements of the assessment object as well as of specific aspects of the changeability, i.e., the mobility. This segmentation is very well suited for the derivation of measures for increasing the changeability of the system, because needs for action can be directly assigned to the individual system elements. However, the risk of not taking element and aspect transcending correlations into account is also present. For example, an easily exchangeable and, thus, performance-wise scalable hydraulic unit of an injection molding machine would be positively rated individually. Yet, if the holms of the injection molding machine have already reached their mechanical limit, a higher clamping force would not able to be achieved despite an enhanced hydraulic performance. The scalability identified on the element level cannot be implemented as an increased production rate on the level of the entire system. Therefore, the lacking element transcending observation would lead to incorrect evaluations.

The method carried out focuses on the physical properties of the system. However, the information-technical structure of the production systems must also be designed to be changeable. A functionally independent module must also be able to be integrated into the control system, for only by means of physical adaptability of the system is changeability truly achieved. The possibility to rearrange process sequences is already a source of great potential. If, for instance, subfunctions of the system elements can be freely combined with one another, the integration of additional work steps is possible to accomplish without problems. For example, a welding process can be extended by means of the assembly of an inlay. Therefore the movement of the main spindle is used as a separate process step for the assembly. This ability could be described as combinability. In regards of the change enablers, they can principally be allocated to modularity and universality. An extension of the method by Drabow by adding according criteria would be conceivable. In this context, the questions concerning the system safety, and whether the machine and production data is ascertainable should be included.

## Conclusion

The method employed by Drabow can also be utilized in the plastics processing environment once several adjustments have been made. It became clear that the pilot plant in particular and changeable production systems for plastics processing in general require further development. Especially in terms of the scalability there is a large potential for improvements.

In terms of the assessment methodology , the aspect of combinability should be taken into account in the evaluation system, in order to include the variability of element transcending processing sequences along with the physical aspects.

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