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THE DEVELOPMENT OF A SYSTEMATIC DESIGN FOR CHANGEOVER METHODOLOGY

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1 Introduction

Flexibility and responsiveness are watchwords of modern manufacturing, driven by a desire to reduce non-value-added activity and better respond to customer demands. Rapid changeover between products is paramount if genuine manufacturing flexibility and efficiency are to be achieved.

Changeover improvement has been in sharp focus as the limitations of the mass-manufacturing paradigm have become increasingly recognised. Shigeo Shingo's SMED (Single Minute Exchange of Die) methodology [1] has come to dominate retrospective improvement practice and his defining work has been interpreted and developed into a variety of training and implementation strategies. Particularly when interpreted by training organisations the methodology is often seen to retain a core objective of translating changeover tasks into external time. In doing so, where improvement by revising work procedures is predominantly emphasised, the methodology can undervalue opportunities to modify process equipment.

Even though a large number of case studies and examples of good design practice can be found from the literature there is no existing formal design for changeover (DFC) methodology. Without comprehensive guidance as to how genuine rapid changeover performance may be incorporated at the design stage those engaged in the design process have no option but to develop equipment changeover capability on an ad hoc basis.

Although a comprehensive DFC methodology is not available, a number of design for changeover rules have previously been proposed [2, 3]. These simpler design rules can be used more generally to direct equipment design. However, these rules do not provide full guidance since they fail to provide means to assess what new equipment's changeover capabilities will be once in service. Equally the rules are unranked, where some rules will be liable to have a far greater impact. Together they do not match the coherence and structure of commercially successful DFX packages, particularly those in the DFA area [4].

This paper shows how a systematic design for changeover methodology can provide strong guidance for equipment designers, and identifies essential characteristics of such a methodology. The proposed DFC methodology has been informed by a review of other DFX methodologies coupled with extensive active industrial research.

1.1 Objectives

The objectives of this paper are:

- To identify DFX methodologies with likely elements of commonality with design for changeover
- To discuss the necessary characteristics for a successful DFC methodology
- To identify similarities and distinctions between a design for changeover methodology and existing DFX methodologies

2 Related Research

Relevant literature can be found in two areas: that relating to changeover improvement (also often called set-up reduction) and that concerned with Design for X (DFX).

Considerable literature is available in both instances. Literature on the topic of changeover improvement can be categorised into papers which describe its **benefit** to modern manufacturing and those which describe **methods** to enact improvement. The current authors have reservations of some literature which discusses achieving improvement, particularly in respect of the emphasis usually accorded to retrospective and organisation-led improvement activity [5]. Concern has also been previously expressed by the authors as to the definition of a changeover. These issues are here briefly revisited. From the literature and from original research over a period of more than ten years the authors go on to categorise and propose primary influences on measured changeover performance.

2.1 Prior Research into Changeover Improvement

Considerable attention has been given to the subject of changeover improvement since the limitations of the *mass manufacturing* paradigm have become understood. Today there is a trend to have shorter runs and more variety and thus to complete ever greater numbers of changeovers on manufacturing equipment. With pressure to enact small batch multi-product manufacture the need for both high quality and rapid changeovers is readily apparent if poor line utilisation and deficient product quality are to be avoided.

2.1.1 Changeover definition

Many authorities give a ‘good piece to good piece’ definition of a changeover. The authors adopt the view, that a changeover is defined by the elapsed period between ceasing full-scale manufacture of the original product through to the establishment of full-scale, full-quality manufacture of the new product [5]. Anything which occurs within this interval is a changeover event.

Figure 2.1 illustrates that a changeover potentially includes three distinguishable phases: run-down and run-up phases as well as the always present set-up phase during which the line is static [5]. There are important implications of including these three phases in the definition. The most notable implication is that markedly differing activities can arise during the successive phases. All of these activities – across the changeover as a whole – need to be addressed within a fully comprehensive DFC methodology. Also important, the run-down and run-up phases together potentially contribute significantly to the overall changeover's duration.

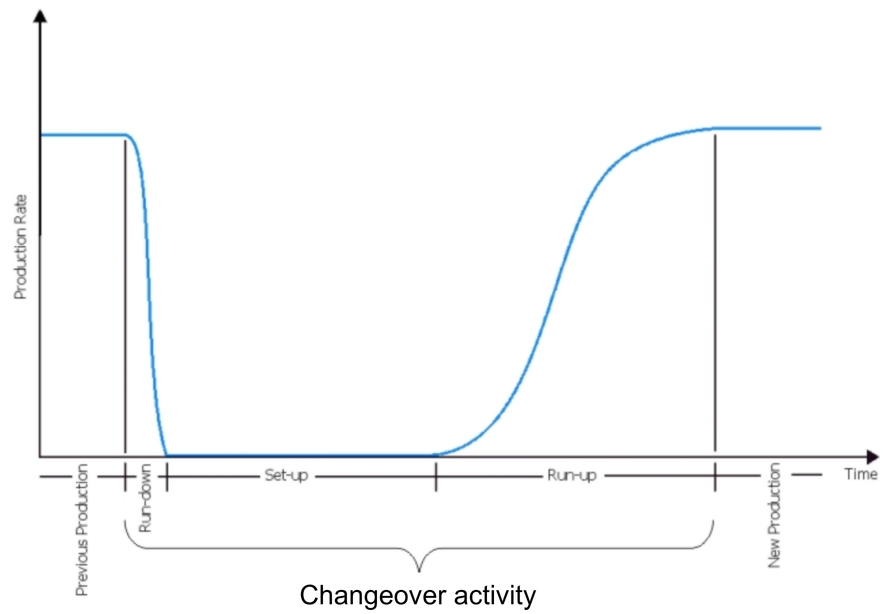

Figure 1 - Typical production rate characteristic during a changeover

As well as identifying that a changeover comprises separate phases, some authorities also argue that what is done during the set-up phase is influential upon what occurs during the run-up phase [6, 7]. In this way seeking to minimise set-up might jeopardise run-up performance. Instead, therefore, a more holistic view is necessary, seeking time reduction across the changeover as a whole and giving attention to the quality to which settings are made.

2.1.2 An organisational bias to changeover improvement

General improvement techniques beyond those applicable to changeovers range from hardware modification through to the control of information and the management, training and motivation of people. The former can be undertaken by original equipment manufacturers (OEMs) or by the equipment users. The latter options largely relate to how people work and are often cited as soft or managerial issues. They are issues which OEMs can have little or no impact upon.

The authors describe that these opportunities can be distinguished as those which are design-led and those which are organisation-led. This universal distinction also applies to changeover improvement activity. The primary distinguishing aspect of organisation-led improvement is that emphasis is placed on changing the way that people work. For changeovers organisation-led improvement occurs, for example, when people complete tasks in a more disciplined manner, or when more appropriate tools are used. Organisational improvement can also predominate when the sequence in which tasks are conducted is altered, including arranging for parallel working to occur, or arranging for tasks to be completed in external time.

By contrast design-led improvement occurs when there is an emphasis on physically altering manufacturing equipment, thereby, typically, necessarily altering the changeover tasks which previously had to be completed [5]. The emphasis is on altering process hardware. An amended changeover procedure will necessarily ensue. In some cases, also representing a design change, the product itself can also be beneficially altered.

It is pertinent to reflect on what can be thought of as the bias that any improvement programme might adopt. This paper discusses that for changeover improvement practice the bias currently falls disproportionately towards organisational refinement, not least because these opportunities are more readily seized upon by management consultants and training organisations, often under the premise of programmes of minimal expenditure.

It is reasonable to argue that such retrospective improvement agencies might be advantaged by a greater awareness of design-led opportunities. The overall need for greater design guidance is still more forcefully apparent in an OEM design context. Whereas retrospective improvement can be undertaken with either an organisation-led or a design-led bias, this option is unavailable to the OEM: original equipment designers can only influence changeover capability by their work prior to equipment installation and commissioning.

2.1.3 Influences upon changeover performance

The foregoing discussion highlights some of the major influences on the actual changeover performance experienced on manufacturing equipment, which comprise elements of both hardware design and organisational refinement.

An overview of these influences is given in Figure 1, showing the 4Ps of changeovers: People, Practice, Process and Products. The motivation of people who conduct the changeover and the work practices they adopt normally receive the greatest attention. In other words retrospective and soft-focussed improvement has predominated.

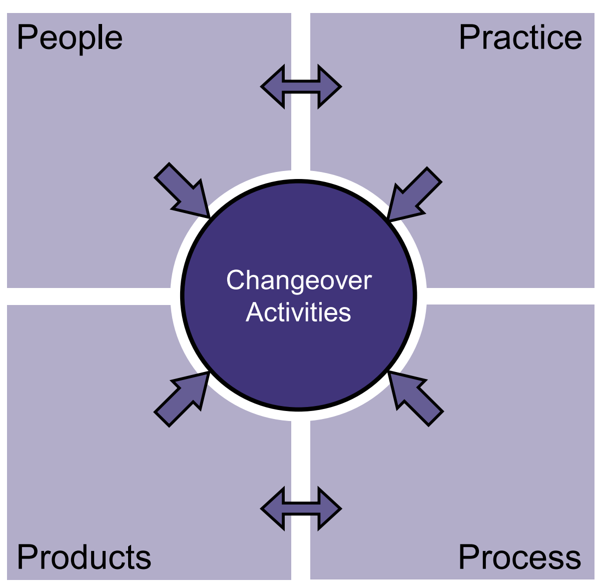

Figure **2**. The 4Ps of changeovers: Main influences on changeover capabilities of manufacturing equipment

There are manifest opportunities to increase the attention given to process hardware and product design. It is to this end, especially for use by OEMs, that a design for changeover methodology is being developed.

2.2 Design for X Methodologies related to Changeover Activity

The need for such philosophies was identified as engineers became increasingly aware of a lack of appropriate detailed knowledge in important product life-cycle processes. Design for X methodologies can be seen as tools to analyse designs for their suitability for certain product life-cycle aspects. Manufacturability and assemblability were among the first life-cycle processes to have been considered since they were highly apparent cost reduction drivers [8]. In particular these tools bring designers and manufacturing experts together and address, typically because of education system shortcomings, lack of manufacturing expertise among designers [8].

Similarly, following the example of DFA and DFM, other DFX methodologies have been proposed to consider life-cycle values, assessing parameters like quality, maintainability, reliability, safety regulations and environmental issues earlier in the design process.

The benefits of DFX tools, which require the involvement of functional experts, are improved performance of products and related processes. DFX methodologies do not necessarily reduce the number of design decisions, but they help to make them earlier in the process. Substantial cost and development time savings can potentially be made as changes are easier to make the earlier they are provoked [9].

As described above, DFX methods are tools to evaluate design concepts or detailed designs and as such provide measures for the cost, quality and regulatory conformity of a certain aspect of a product's life-cycle[10]. Thus, not only providing a benchmarking tool for designs, but also providing some form of indication of what the possible relative benefits of one design are compared to another.

The most prominent and widely used DFX methodologies are Design for Assembly (DFA) and Design for Manufacture (DFM). DFA provides methods to evaluate assemblability, assembly times and costs of a product. DFM helps the designer to increase the manufacturability and to provide accurate manufacturing costs for a product and its components. Complex cost models have been developed for different manufacturing processes and their process parameters [4, 11].

Boothroyd and Dewhurst [4] have linked those two tools to explore possible trade-offs between assembly and manufacturing costs. Setup times are considered in their work and are included in their cost models as average time estimates or supplier information and are treated as constants in the calculations. However, differences in changeover times between various processes can not be determined accurately. Changeover times, however, are strongly dependent on the product range and the manufacturing process. One objective of DFC is to allow more accurate estimates of changeover capabilities of manufacturing equipment and the influences product and variant design have on it.

Design for Maintenance or Design for Service (DFS) considers how subassemblies can be exchanged as quickly and easily as possible. Depending on the relative likelihood of failure of a certain component or subassembly more effort into improving maintainability, mainly disassemblability and assemblability, of this component is justified.

Assembly and disassembly tasks are major parts of almost every changeover and thus DFA and Design for Disassembly need to be taken into account when designing equipment with good changeover capabilities. However, a modular approach is necessary, since not every part is individually assembled or disassembled. Also, different criteria apply, depending whether change elements are necessary or not.

2.2.1 Design for Manufacturing Flexibility

Current research into manufacturing systems is looking into changeable and reconfigurable manufacturing systems in order to better react on variations in product characteristics, product mix and volume. Schuh *et al.* [12] developed a Design for Changeability method, which allows manufacturers to determine the right degree of flexibility. Using a modular approach, Schuh *et al.* [12] are distinguishing between unstable and stable elements of the production system. Unstable or time variant elements are encapsulated as modules; stable or non-variant elements are encapsulated in platforms.

It is argued that the changeability of a manufacturing system is determined by a limited number of “change drivers”. These change drivers represent the variations in product characteristics, capacity requirements, differing degrees of automation or adaptations due to changes in standards or location of production. The production structure matrix developed by Schuh *et al.* [12] maps change drivers to modules of the production systems and indicates which modules are affected by which change driver. This matrix can then assist in seeking improvements by changing the process configuration, by integration or separation of production elements or reduction/elimination of the influence of a change driver on a certain production element.

Although Schuh *et al.* [12] offer a useful tool to analyse the right degree of flexibility for a specific production environment, they do not include the activities of actually changing the production system from one configuration to a new configuration in their considerations. A disadvantage of this approach is that it does not allow changeover times to be estimated and thus assess lead times during the design process.

2.2.2 Design for Changeover Contribution

Design for Changeover can be seen as an expansion of Schuh’s modular plant architecture [12] combined with methods similar to Design for Assembly, Design for Disassembly and Design for Maintenance in order to consider changeover activity.

As well as the methods described above DFC needs to incorporate the following:

- Modules can be seen on all levels of production elements. In addition to Schuh’s approach product commodities and other change elements must be considered

- Metrics specific to changeover to evaluate different designs must be developed including time, cost and quality of changeovers caused during all phases, including run-down, set-up and run-up

- Although design-led improvements are suggested [12] to eliminate influences of change drivers on production elements, no design guidance is provided.

3 A systematic Design for Changeover Methodology

As described earlier, the aim of the proposed DFC methodology is to provide assistance to designers through the design and development process of manufacturing equipment. The overall process of such a methodology is shown in Figure 3.

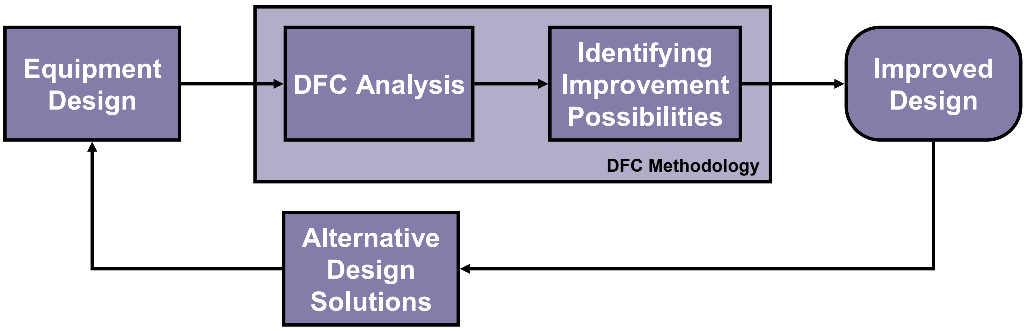

Figure 3. Flowchart of the Design for Changeover Process

The proposed approach for a DFC Analysis can roughly be divided into the following five steps:

- Modelling the changeover process
- Design evaluation for equipment and products
- Changeover activity evaluation
- Changeover activity sequence generation
- Benefit analysis (Impact Analysis, Changeover time estimation, Cost models, etc.)

It is proposed that this will be coupled with some form of expert system to further assist the designer by providing:

- Assistance in identifying improvement opportunities
- Additional assistance by supplying context based design rules

This paper will now present the authors' research on modelling changeover activities and show how changeover performance can be analysed based on this model.

3.1 Modelling the Changeover Process

The changeover process can be defined as a set of activities necessary to correctly set or position certain elements in order to produce the new product at the desired quality at the desired output rate. The authors will refer to these elements as change elements, and to the associated activities as changeover activities.

The effort necessary for a changeover is determined by the number of these changeover activities and change elements and the effort required.

Change elements can have two dimensions, representing either physical objects or process parameters. This is illustrated in Figure 4. Usually the majority of change elements can be considered as physical objects, like equipment parts (change parts and other parts) or parts of the product and product commodities. However, other physical entities like levels of electrical voltage, heat flux, hydraulic or pneumatic pressure etc. can also be seen as change elements, if these have to be changed during a changeover. A changeover activity would then be the change from one level of such a unit to another level.

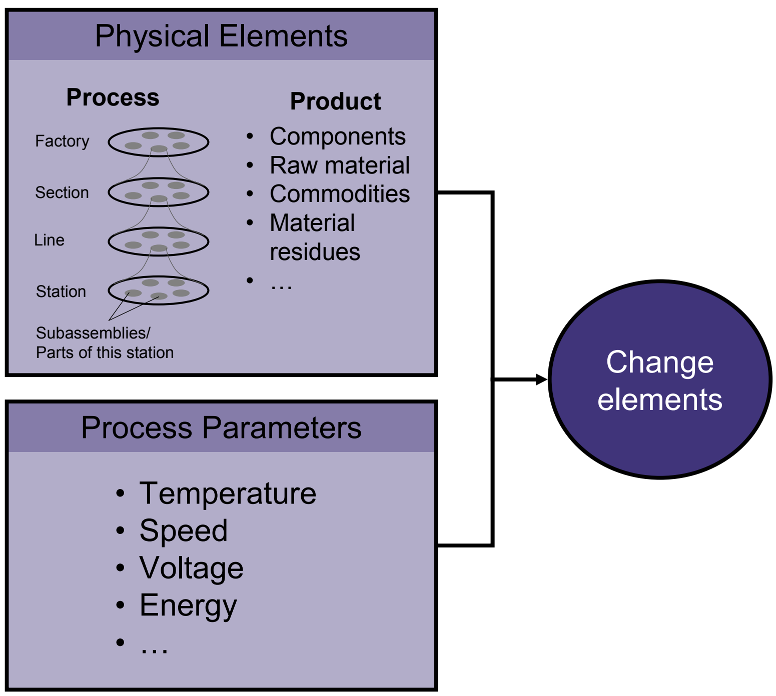

Figure 4. Change elements during a changeover of manufacturing equipment (Developed from [12]).

Change elements representing objects can be either process or product elements. On the process side physical change elements can be described as modules similar to Schuh's approach [12], where only the unstable elements are considered individually. All other elements are considered as platforms. On the product side, change elements can be considered to be subassemblies or components of the product or other product commodities.

Depending on relative differences between the product in production before the changeover and the product in production after the changeover, changeover times often vary considerably. In one case a changeover might only involve changing one machine of a manufacturing line, and in another case all line stations have to be changed.

The concept of a change element and the association of activities to change elements is a fundamental concept of the proposed DFC methodology.

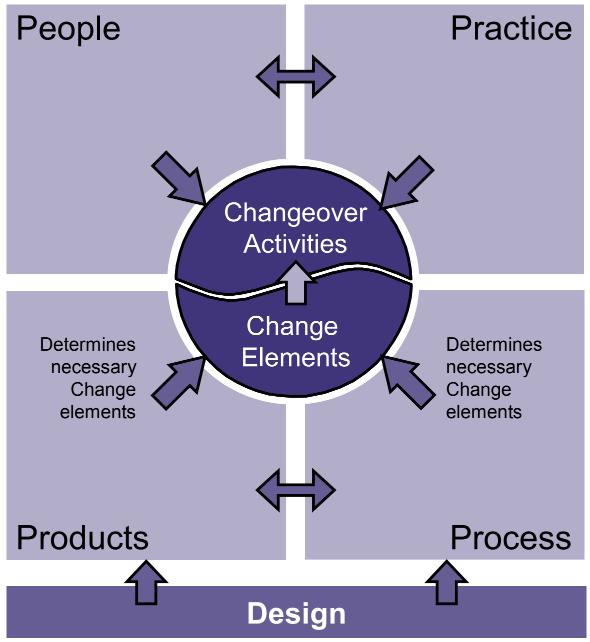

Figure 5. Enhanced 4P diagram: Elements of a changeover and their impact on each other

The circle in the middle of the Figure 5 illustrates a changeover consisting of changeover activities and change elements. In general the nature of a change element combined with its relation to certain product characteristics defines the level of activity necessary to change this element. This relation between change elements and associated changeover activities is illustrated by the arrow in the centre of Figure 5.

As the figure shows, change elements can not be influenced by the people performing the changeover or by workplace organisation, unless design-led improvements are utilised.

The potential for design can be twofold: On the **product side,** variety in product characteristics, causing the necessary changes during a changeover, can be reduced or eliminated. On the **process side,** unnecessary change elements can be eliminated. In addition, the influence of a change driver on the necessity to change a certain process element can be eliminated.

Figure 6 illustrates the different aspects of change drivers, product mix and output volume. Change driven by the product mix can be described by the product structure and product parameters.

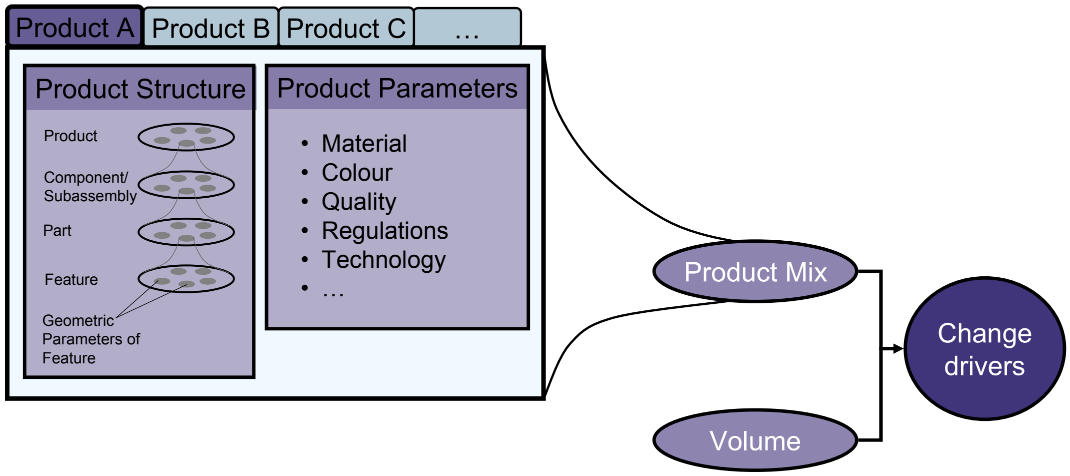

Figure 6. Drivers for changeovers (Developed from [12]).

3.2 Analysing the DFC model

The next stage is to undertake some form of analysis of a changeover. From a design point of view the two entities describing a changeover are the change elements involved in the changeover and the changeover activities associated with them.

The authors propose an approach where changeovers are analysed in two parts, one focusing on the change elements, the other focusing on the changeover activities. Central to the analysis of changeovers is distinguishing between essential and non-essential change elements and necessary and unnecessary changeover activities.

The two parts of the DFC Analysis are:

- The Design Efficiency Analysis. Equipment design evaluation by comparing necessary and unnecessary change elements.

- The Changeover Activities Analysis: Evaluation of the changeover activities.

The non-essential elements and activities are candidates for elimination. If this is not possible the Changeover Activities Analysis guides redesign of change elements to ease changeover activity

It is noted that these analyses concentrate on equipment design. However, a product design's suitability for flexible manufacturing within a certain manufacturing environment can also be benchmarked by using these analyses.

The following sections will provide more detailed information on these two types of Analyses.

3.2.1 Design Efficiency Analysis

DFA uses its central criteria to determine whether a part is necessary or unnecessary and therefore whether any possibility for improvement exists. Similarly, criteria can be developed to distinguish between necessary and unnecessary change elements.

Non-essential change elements can easily be identified by asking:

> "Does this change element have any functional contact with the product in any form at any time throughout the entire manufacturing process of the product?"

If the answer is no for a particular element, then this element is an unnecessary change element and a candidate for elimination.

Further reduction of necessary change elements can be achieved by either:

- **Elimination** of influences of change drivers on specific change elements, for example, by questioning the necessity of a contact between the product and a change element during the manufacturing process

- **Combination** of a number of necessary change elements into groups of change elements, which can be changed together as one change element

The elimination of influences of change drivers on specific change elements can have a product and a process design aspect. The choice is either to reduce the product variety or to design flexibility into the affected change elements. Respectively, these strategies eliminate a change driver or accommodate product variety.

3.2.2 Changeover Activities Analysis

The Changeover Activities analysis focuses on the assemblability and disassemblablity of change elements. This is done in a similar way to DFA methods [4, 11, 12].

In addition to disassembly and assembly tasks, a considerable part of changeover activity relates to setting and adjustment, often because repeatability and accuracy of setting right-first-time cannot be guaranteed. Reasons for this include variations in the product, materials or in the process itself. Although there are some cases where product variety cannot be avoided, for example when processing fruit yoghurt, process and product designers should generally aim to eliminate this variety. Therefore, a penalising mechanism has been developed for adjustment operations.

3.3 Developed methods

As the result of the above described research a spreadsheet based tool has been developed to analyse manufacturing equipment. This is shown in Figure 7.

original design																		
change elements		Changeover Activities														Changeover Analysis		
change element	No. of elem.	fetching			handling	releasing	extracting	positioning	inserting	securing	operation time (excl. fetching time)	adjustment?	add. t to remove other elem.	add. time for check.	total adjustm. time	elem. c/o time	nec. CE	nec. CE c/o time
	N	grasped together?	time/s	total time/s	time/s	time/s	time/s	time/s	time/s	time/s	time/s	A_a	T_{aot}	T_{ac}	$T_{at}=T_{aot+Tac+Tp}$		E_n	
jigs	2	0	40.8	81.6	9	0	4	0	4	0	17	0				115.6	2	34
											0	0						0
disc	1	0	12.41	12.41	1.69	0	2.5	0	2.5	0	6.69	0				19.1	0	0
											0	0						0
binary dec.	2	0	0	0	0	0	0	10	0	0	10	0				20	0	0
screws	4	0	0	0	0	0	10.5	0	10.5	0	21	0				84	0	0
											0	0						0
electrodes	2	1	8.6	10.28	5.6	0	6.5	5.5	6.5	0	24.1	1	20	30	55.5	169.48	2	48.2
screws	8	0	0	0	8	0	6	0	6	0	20	0				160	0	0
bolts	2	0	0	0	1.13	0	5	0	5	0	11.13	0				22.26	0	0
totals	21														sum:	590.44	4	82.2
			NON-VALUE ADDED														design efficiency	c/o activities
																Index	19.05%	13.92%

Figure 7. Developed tool to analyse changeover capabilities

Using this tool different equipment designs, either existing or conceptual, can be evaluated. Relative benefits in terms of changeover performance are indicated by design efficiency and changeover activities indices.

4 Conclusions

This paper gives an overview of the work currently being conducted by the authors on the subject of design-led changeover improvement.

It has been shown that there are important similarities between changeover activities and those which occur within assembly, disassembly and maintenance processes. However, there are also significant differences, which have to be addressed accordingly. This paper points out these distinctions and proposes a possible approach for a design for changeover methodology.

The further development and validation of the proposed DFC methodology is part of an ongoing research project on DFC by the authors. Future research on the integration of an expert system providing design guidance and the integration of methods to provide financial justification to improve changeover performance is planned.

Acknowledgments

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