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An Industry-Applicable Screening Tool for the Clarification of Changeability Requirements

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Abstract. Manufacturing companies need changeability in order to adapt to change drivers, such as unpredictable market demand and increasingly relevant sustainability requirements. Specific change drivers determine different changeability requirements, thus leading to the need for different changeability enablers. Therefore, before starting the identification and design of changeability enablers, companies should effectively identify their changeability requirements. In this study, an industry-applicable screening tool for the clarification of changeability requirements is proposed. The tool allows companies to discern whether they need flexibility or reconfigurability enablers. The tool has been validated with industry experts and is ready to be disseminated in industry.

Keywords: Changeable Manufacturing, Reconfigurability, Change Drivers, Changeability Requirements, Industry-Applicable Tool.

1 Introduction

Manufacturing companies are exposed to increasingly frequent and unpredictable market changes, including the rapid introduction of new products, shorter product lifecycles, and constantly varying product demand [1,2]. Moreover, the increasing need to be sustainable pressures companies to adapt products and manufacturing processes to new regulations and requirements [3,4]. Changeability is a necessary ability for manufacturing companies to withstand such turbulent scenario in a quick and cost-effective way [5]. Focusing on individual factories - i.e. sets of manufacturing and logistics systems directly and indirectly responsible for the manufacturing of specific product groups - changeability is achieved recurring to reconfigurability and flexibility [5]. Both the concepts of flexibility and reconfigurability deal with modifications in manufacturing systems and their distinction is in the timing, cost, and number of steps necessary to implement modifications [6]. Specifically, flexibility allows fast adaptation within narrow corridors of change [7]. At some point during system lifecycle, the necessary flexibility may be already available or may be absent. If absent, it may be acquired and, to do so, the system must be reconfigurable, i.e. already predisposed to afford such acquisition. Unlike flexibility, reconfigurability actions require higher, but adequate effort in

terms of reasonable time and low costs in order to allow any change (thus, not within a predetermined range of change).

Both contextual and internal change drivers influence manufacturing companies. For example, a specific company might need to adapt processes to upcoming sustainability standards or adapt both products and processes to a new market need or output volume. However, how and to what extent change drivers affect the manufacturing company differs across companies [8] and determines distinctive and company-specific changeability requirements. Moreover, there is no universal way to achieve changeability, but many researchers have contributed to identify a variety of changeability enablers [9–12]. These enablers should be selected based on these distinctive changeability requirements of manufacturing companies [13]. The overall process of analysis of requirements and development of changeability enablers can thus be divided into three sequential sub-processes:

1. Identification of changeability requirements, based on change drivers: definition of companies' need for changeability and expected changes;
2. Assessment of the existing changeability enablers: analysis of the existing ability of the manufacturing system/s to meet changes and definition of changeability enablers to meet the requirements;
3. Development of the required changeability enablers: development of design concepts of changeability enablers, allowing the company to fill the gap between changeability requirements and existing changeability enablers.

Therefore, it is critical for manufacturing companies to start from the identification of changeability requirements (first-sub-process) in order to appropriately improve the existing changeability enablers or acquire the required ones. For this reason, this study addresses the following research question: “*What practical tool can be provided to manufacturing companies to allow the clarification of their distinctive changeability requirements?*”

2 Literature Review

A structured literature review [14] has been conducted in the following four stages.

In stage one, the objective of the literature review has been defined: the identification and analysis of already existing tools for the clarification of changeability requirements.

In stage two, the literature search has been performed. The search database used to find literature is Scopus. The research domain has been defined using the following search string: ("changeability" OR "reconfigurability") AND ("manufacturing") AND ("need" OR "requirement" OR "change driver") AND ("assessment" OR "clarification" OR "identification" OR "specification"). Moreover, the following inclusion criteria have been applied: only (i) articles published within the last 10 years and (ii) written in English have been selected. In this way, 26 articles have been identified. After a preliminary analysis of their abstracts, 15 pertinent articles have been selected.

In stage 3, the pertinent literature has been analysed in detail and described in an Excel database. Considering the three sub-processes of the analysis of requirements and

development of changeability enablers introduced in Section 1, five articles focused on the identification of changeability requirements have been finally selected.

In stage four, the results of the analysis of the five articles focused on the identification of changeability requirements have been reported as these provide the theoretical ground of this study. Specifically, two of the five articles actually provided and described tools for the clarification of changeability requirements: these are Garbie and Parsaei [15] and Andersen et al. [13]. Among these two articles, Andersen et al. [13] not only provided a procedure for the specification of changeability requirements, but also demonstrated applicability in industry, in both existing and new systems. The remaining three articles still provided interesting insights for the development of the tool proposed in this study. Dit Eynaud et al. [11] directed to two already existing questionnaires (provided in Andersen et al. [12] and Maganha et al. [14]) that can be exploited to identify changeability requirements. Karl and Reinhart [16] listed and specified manufacturing resources-relevant influencing factors leading to changeability requirements and provided axes for mapping the requirements. Benkamoun et al. [17] provided an overall framework for designing changeability from the outset which clarifies concepts and terminology.

3 Methodology and Tool Development

The tool proposed and presented in this paper was developed in a research project that aims to develop and disseminate industry-applicable tools for the design of changeable and reconfigurable manufacturing. The project involves collaboration with various manufacturing companies transitioning towards changeable manufacturing.

The methodology adopted in this study consists in two steps: tool development and tool validation. Specifically, the two steps have been sequentially implemented in several iterations, following the Delphi Method and adjusting the tool based on the feedback of four of the companies participating in the project.

The development of the tool takes outset in the tool provided by Andersen et al. [13], which has been adapted based on the need to: (i) enhance the understandability in industry, and (ii) provide an exhaustive analysis of change requirements considering insights from other analysed literature.

Andersen et al.'s tool implies: (i) the collection of facts through a questionnaire and (ii) the interpretation of these facts by associating them to requirements in terms of flexible, dedicated or reconfigurable manufacturing systems. Thus, a company applying such tool gets an overview of how its change drivers lead to a combination of requirements belonging to flexible, dedicated and reconfigurable systems.

Andersen et al.'s tool has been modified as follows.

- With regard to the collection of facts, the questionnaire has been modified.
 - The questions of the questionnaire proposed in this study cover three areas as drivers of changeability requirements: (i) product, (ii) production, and (iii) technology and sustainability.
 - In each of these areas, individual questions require respondents to indicate present or expected levels of change. Specifically, respondents need to select an option

within five choices ranging within five levels: very low (1), low (2), medium (3), high (4), and very high (5).

- With regard to the interpretation of collected facts, the criteria for interpretation have also been modified.
 - The distinction in requirements associated to either flexible, dedicated or reconfigurable manufacturing systems has been overcome since, taking a changeability perspective, flexibility, reconfigurability and dedication are not opposite concepts but can overlap and coexist in changeability enablers. To prepare the ground for the following phase of identification of changeability enablers, the identification of changeability requirements should be as clear as possible.
 - The developed tool should allow a company to discern between short-term changeability requirements, associated for example to the need to conduct changeovers when switching across product variants, and long-term requirements, associated for example to the need to introduce new sustainable materials.
 - Thus, in the tool proposed in this study, change requirements have been classified according to the three categories identified by Tracht and Hogleve [18]. These categories are: (i) change requirements in product/part variants, (short-term changeability requirements); (ii) change requirements in production capacity, (mid-term changeability requirements); and (iii) change requirements in product features (long-term changeability requirements).
 - The collected facts can thus be mapped on three graphs, belonging to these three categories of change requirements.

As anticipated, the aforementioned changes to the tool have been validated following the Delphi Method. The involvement of the four companies through the Delphi Method has ensured that the developed tool can be both effective and easily used by companies. At each company, one main stakeholder – usually the production manager – has been involved. The Delphi Method has been conducted in five rounds: (i) one for each of the involved companies (where the feedback from individual stakeholders was exploited to improve both understandability and effectiveness of the tool), and a final common round (consisting in the finalization of the tool and the illustration of the results of its implementation at each of the companies).

4 Illustration of the Tool

The tool provided in this study consists of an Excel questionnaire which, once filled by relevant company's stakeholders, allows an automatic visualization of the results.

An extract of the questionnaire is provided in the following Fig. 1.

As shown in Fig 1., stakeholders filling the questionnaire have the possibility to differentiate answers for selected product/part families, so to allow the comparison of the corresponding changeability requirements.

After collecting facts by answering to the questionnaire, companies get an automatic quantification of their changeability requirements and can visualize them on three graphs – corresponding to change requirements in product variants, product capacity, and product features -as exemplified in Fig. 2. When change requirements in product

variants (short-term) prevail, companies need to consider flexibility enablers rather than reconfigurability enablers. Conversely, when change requirements in production capacity (mid-term) and/or product features (long-term) prevail, companies need reconfigurability enablers. In the example of Fig. 2, changeability requirements for Product A are very important, this is especially true for Variant and Product changeability; conversely, capacity changeability requirements look stable. With regard to Product B, changeability requirements do not appear important.

Thus, by simply answering to the questionnaire, manufacturing companies can assess their changeability requirements and understand not only whether they need variety, capacity or product changeability, but also to what extent the different categories are required. Indeed, as shown in Fig. 2, the possibility to see not only the average value of changeability requirements, but also the entire distribution of requirements on axes eventually allows deriving interesting observations regarding specific parameters particularly affecting the results of the analysis.

Three covered areas: (i) product (focus of this example), (ii) production, and (iii) technology and sustainability.		Possibility to differentiate answers for selected product/part families		Drop-down list of options ranging from VL to VH for the great majority of answers (e.g. Comparison with the Industry)	
		TYPE HERE THE FOCUSED PRODUCT/PART A		TYPE HERE THE FOCUSED PRODUCT/PART B	
PRODUCT QUESTIONS		Standard answers (type/select your choice)		Standard answers (type/select your choice)	
Variety		answer part 1	answer part 2	answer part 1	answer part 2
q1	How many product/part variants exist? For your specific industry, is that considered Very High (VH), High (H), Medium (M), Low (L) or Very Low (VL) variety?	<i>type number of variants</i>	<i>Comparison with the Industry</i>	<i>type number of variants</i>	<i>Comparison with the Industry</i>
q2	How is product/part variety expected to evolve in the next 3-5 years? And what is the main driver for change?	<i>VL - strongly decrease L - decrease M - remain the same H - increase VH - strongly increase</i>	<i>type main driver/s for change (e.g. new materials, new sizes...)</i>	<i>VL - strongly decrease L - decrease M - remain the same H - increase VH - strongly increase</i>	<i>type main driver/s for change (e.g. new materials, new sizes...)</i>

Fig. 1. An extract of the questionnaire

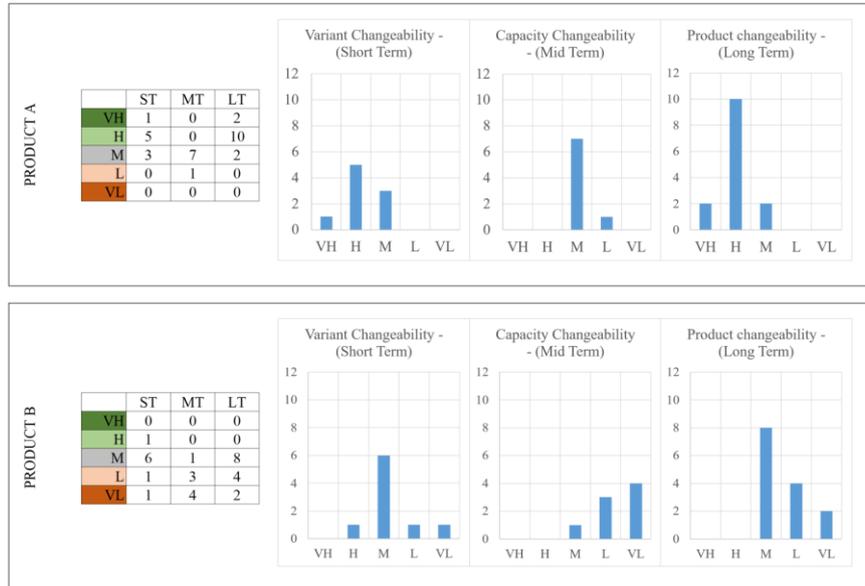


Fig. 2. Example of visualization of changeability requirements

5 Conclusions

In this study, a tool for the clarification of changeability requirements is provided and is meant to be industry-applicable. It represents an extension of an already existing procedure for the specification of changeability requirements that has proved scientific validity and applicability in industry. Moreover, the involvement of four companies for the validation of the tool has ensured its effectiveness.

The contribution for practitioners of this study is the provision of a tool aimed to be universally used by companies: it considers diverse change drivers and corresponding changeability requirements, so that disparate and distinctive manufacturing companies can practically use it to identify those specifically regarding them. Moreover, the tool can be autonomously used by companies. The involvement of companies in the process of building this tool has extensively contributed to the industrial applicability of the tool itself.

The theoretical contribution of this research lies in the attempt to provide a tool that allows to differentiate between short-term changeability requirements, which, can be addressed by companies by investing in flexibility enablers, and long-term changeability requirements, which – conversely – can be addressed by investing in reconfigurability enablers. To this regard, distinguishing between these two kinds of requirements is relevant because literature has addressed them in different ways, thus providing different solutions. As stressed in section 1, unlike flexibility, reconfigurability solutions require higher, but adequate effort in terms of reasonable time and low costs in order to allow any change (thus, not within a predetermined range of change). Moreover, since

the questionnaire also ensures the collection of facts related to expected product evolution due to the increasingly relevant sustainability requirements, (which lead to change requirements in product features, i.e. long-term changeability requirements), the tool also makes evident the impact that sustainability requirements have on the need of companies for reconfigurability enablers. To this end, further research should aim at applying the tool in a consistent number of manufacturing companies, so to quantitatively show the impact of sustainability requirements on the need for reconfigurability enablers.

As the tool allows companies to clarify the nature of their changeability requirements, future research should also aim at supporting companies in the following step, which is the identification of concrete instances of flexibility and reconfigurability enablers that would allow them accommodating the identified requirements.

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