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DEVELOPING MASS CUSTOMIZATION IMPLEMENTATION GUIDELINES FOR SMEs

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Table of abbreviations

Abbreviation	Full name
ATO	assemble-to-order
BOM	bill of materials
CODP	customer order decoupling point
EPC	engineering-procurement-construction
GA	grid area
GT	group technology
HPU	hydraulic power unit
IGs	implementation guidelines
M	product modularization
MC	mass customization
MC-IGs	mass customization implementation guidelines
MES	manufacturing execution system
MPCS	material planning and control system
P	form postponement
PC	IT-based product configuration
PM	process modularity
PP	product platform development
PPCS	production planning and control system
S	part standardization
SC	sourcing configurations for MC
SME	small and medium enterprise
SMED	single minute exchange of die
SW	software
VBTO	virtual build to order

Abstract

Mass customization (MC), an organization's ability to provide customized products and services that fulfil each customer's idiosyncratic needs without considerable trade-offs in cost, delivery and quality, is gaining importance as a production and marketing strategy for companies. The MC literature describes a number of successful stories of MC implementation. However, most companies are not textbook examples of best practices. On the contrary, MC implementation is not an easy process, and winding, uneven, blocked or interrupted paths toward MC are not unusual. To help practitioners on this complex path towards MC, academic research over the years has provided some guidelines for MC implementation. Still, a preliminary review of MC literature has shown that research dealing with MC implementation guidelines is still emerging. Moreover, the main properties and building blocks of MC implementation guidelines have not been identified. Furthermore, small and medium enterprises (SMEs) have emerged as a specific applicability context that is in need of MC implementation guidelines, but have hardly been addressed in the available MC implementation guidelines. In order to narrow this research gap, the present dissertation aims to develop guidelines to help SMEs select MC enablers and sequence them to develop MC capability. This objective has been reached through three research phases. In the first research phase, through a review of the MC implementation guidelines literature, it was possible to identify eight MC enablers in the available guidelines as well as the main properties of the MC implementation guidelines, the building blocks of the MC implementation guidelines, and opportunities for improvement in the MC implementation guidelines. In the second research phase, an MC maturity grid was developed as a core part of new MC implementation guidelines for SMEs. The MC maturity grid was evaluated through an observational evaluation and a long-term observational evaluation in two SMEs. Finally, in the third research phase, new MC implementation guidelines for SMEs are proposed based on the findings from the first two research phases.

Introduction

Mass customization (MC) is defined as an organization's ability to provide customized products and services that fulfil each customer's idiosyncratic needs without considerable trade-offs in cost, delivery and quality (Pine II 1993; Liu, Shah, and Schroeder 2006; Squire et al. 2006). Literature reviews in the field of MC emphasize the managerial relevance of this topic (Da Silveira, Borenstein, and Fogliatto 2001; A. Kumar, Gattoufi, and Reisman 2007; Fogliatto, da Silveira, and Borenstein 2012; Ferguson, Olewnik, and Cormier 2014; Sandrin, Trentin, and Forza 2014). Researchers agree that MC can provide a competitive advantage (Kotha 1995; Da Silveira, Borenstein, and Fogliatto 2001; Holweg and Pil 2004; A. Kumar 2004; Salvador, De Holan, and Piller 2009; Lihra, Buehlmann, and Graf 2012; Lin, Ma, and Zhou 2012).

The MC literature describes a number of successful stories of MC implementation, such as Dell (Selladurai 2004) and the National Bicycle Industrial Company (NBIC) (Kotha 1995). However, 'most companies […] are not textbook examples of best practice' (Comstock, Johansen, and Winroth 2004, 362) and, hence, 'managers need to tailor the [MC] approach in ways that make the most sense for their specific businesses' (Salvador, De Holan, and Piller 2009, 72). This tailoring process is not an easy one; in fact, winding, uneven, blocked or interrupted paths toward MC are not unusual (Pine II, Victor, and Boyton 1993; Kakati 2002; Selladurai 2004; Pollard, Chuo, and Lee 2008; Salvador, De Holan, and Piller 2009). It is recognized that to achieve MC, companies have to go through a complex transition process (Pine II 1993; Piller 2004). This transition requires putting multiple enablers in place (Da Silveira, Borenstein, and Fogliatto 2001; Ma, Wang, and Liu 2002; Salvador, Forza, and Rungtusanatham 2002; Hernandez, Allen, and Mistree 2003; Piller, Moeslein, and Stotko 2004; Blecker and Abdelkafi 2006; Krishnapillai and Zeid 2006; Q. H. Yang et al. 2007; Shamsuzzoha, Kyllönen and Helo 2009; Daaboul, Bernard and Laroche 2012; Fogliatto, da Silveira, and Borenstein 2012; Purohit et al. 2016), coping with a number of hindrance factors (Rungtusanatham and Salvador 2008) and a context-dependent implementation process (Pine II 1993, 132; Da Silveira, Borenstein, and Fogliatto 2001; Salvador, Forza, and Rungtusanatham 2002b; McIntosh et al. 2010; Salvador, De Holan, and Piller 2009). Companies implementing MC must decide which enablers to put in place, how to implement each enabler, the order in which to implement the various enablers, which resources to allocate and which other specific issues require their attention.

Over the years, academic research has provided some guidelines for MC implementation to help practitioners cope with the complexity of MC (Jiao and Tseng

1999; Blecker and Abdelkafi 2006). The development of MC implementation guidelines (MC-IGs) is an academic research endeavour that is specifically designed to transfer accumulated MC knowledge into practice. Unfortunately, MC-IGs have received limited attention in previous MC literature reviews (cf. Da Silveira, Borenstein, and Fogliatto 2001; A. Kumar, Gattoufi, and Reisman 2007; Fogliatto, da Silveira, and Borenstein 2012; Ferguson, Olewnik, and Cormier 2014; Sandrin, Trentin, and Forza 2014). Nonetheless, most of these reviews have called for more research in MC-IGs (Da Silveira, Borenstein, and Fogliatto 2001; Fogliatto, da Silveira, and Borenstein 2012; Sandrin, Trentin, and Forza 2014).

There is also an underlying assumption that MC-IGs could greatly assist small and medium enterprises (SMEs) in MC implementation. This assumption is grounded in the fact that more and more SMEs have to provide personalized solutions at affordable costs, leading to a need for MC implementation in these enterprises (Svensson and Barfod 2002). However, SMEs also lack resources (Brown and Bessant 2003). Thus, 'while larger organizations by their nature can afford the risk of making mistakes, SMEs are typically more vulnerable and, hence, need a structured low risk approach' (Ismail et al. 2007, 86).

This research starts from the assumption that a structured low-risk approach is achievable by providing SMEs with guidelines for implementing MC. Unfortunately, coherent guidelines specifically designed to help SMEs identify feasible improvements towards MC are not provided in the MC literature. As a result, there is a research gap in the intersection of mass customization, implementation guidelines and SMEs. Thus, after preliminary inquiries, the research objective for this PhD research was set as follows: *Develop guidelines to help SMEs select MC enablers and sequence them to develop MC capability*.

In order to fulfil the PhD research objective, the research was divided into three research phases (Figure 1):

(1) Systematic review of the relevant MC literature
(2) Development and testing of the MC maturity grid
(3) Proposal for new MC implementation guidelines

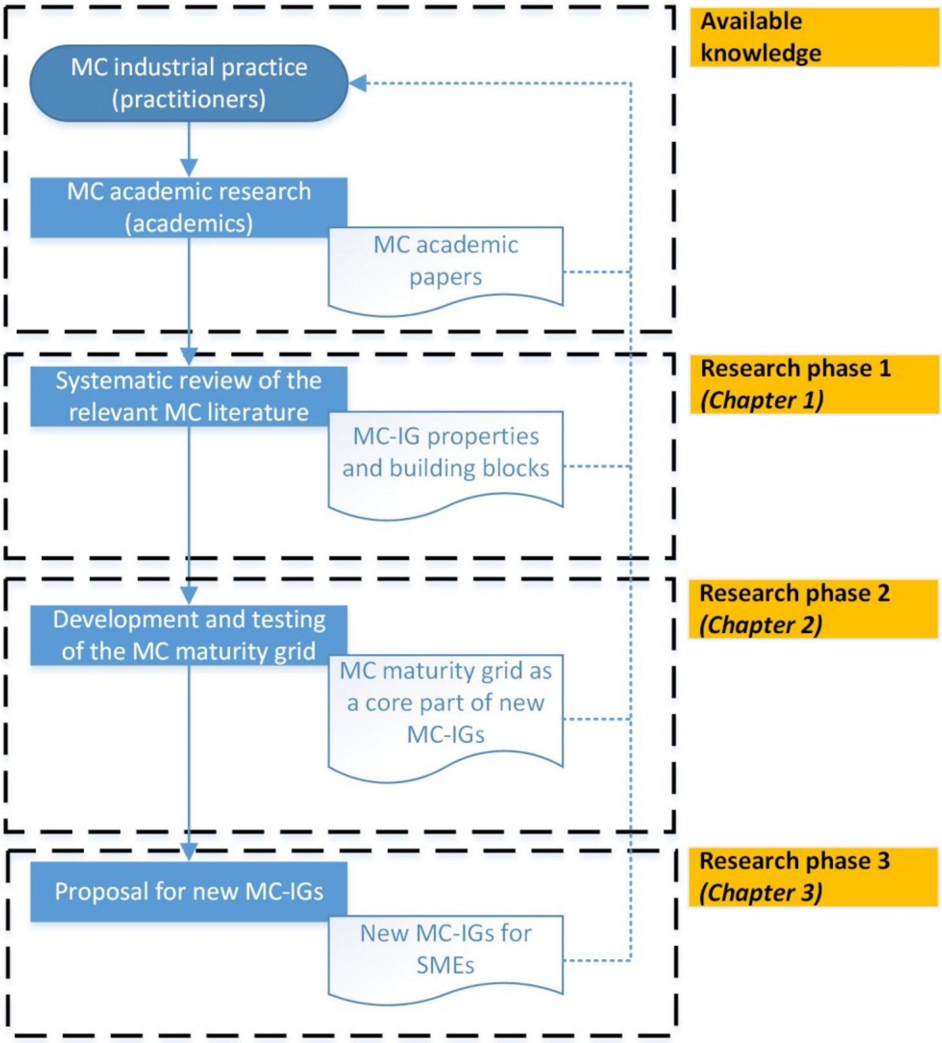
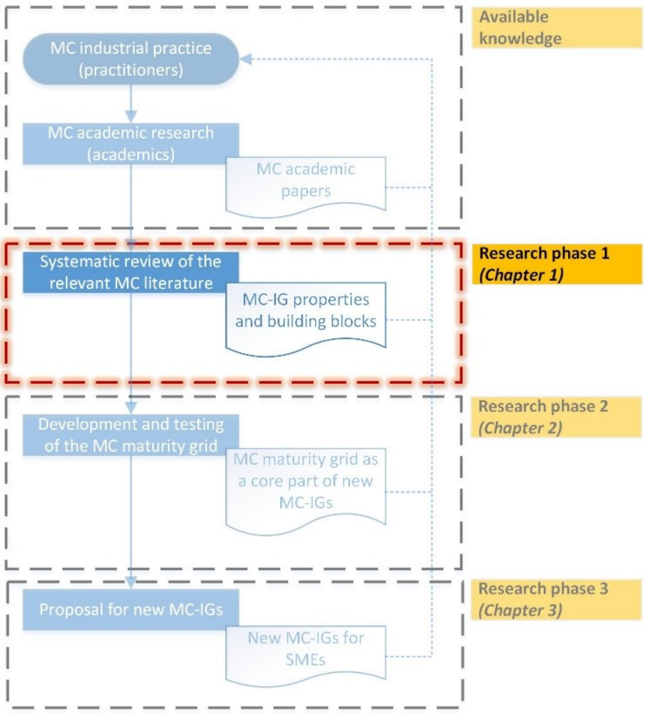


Figure 1. PhD research flow

The dissertation is composed of three chapters, each presenting one research phase (Figure 1). The dissertation ends with the Discussion and Conclusions, providing an overview of the research contributions, research limitations and future research opportunities.

CHAPTER 1: Systematic review of the relevant MC literature

Chapter Summary



In the first research phase, a systematic review of the relevant MC literature was conducted. The relevant articles dealing with MC implementation guidelines were identified and analyzed in depth. This in-depth analysis enabled the development of an inductive coding scheme through a number of iterations and refinements. The application of this inductively derived coding scheme allowed a deep understanding of the MC implementation guidelines currently available in the literature and provided a number of indications for enhancing the research in this MC sub-field. More specifically, it allowed to identify the properties of MC implementation guidelines (context-dependent property, holistic property, and detailed and user-friendly description property), to identify eight MC enablers considered in these guidelines (product platform development, product modularization, part standardization, IT-based product configuration, group technology, form postponement, process modularity and sourcing configuration for MC), to identify seven building blocks of MC implementation guidelines (MC overview, applicability context of the guidelines, required resources, as-is analysis tools, hindrance factors, instruction contents, and instruction exemplification) and to identify opportunities for improvement of MC implementation guidelines.

1.1 Literature review method

The literature review is a method suitable for summarizing the state of the art in the subject field and for identifying future research opportunities (Rowley and Slack 2004). In order to perform the literature review rigorously, a method must be clearly defined (Tranfield, Denyer, and Smart 2003; Rowley and Slack 2004; Seuring and Gold 2012). Consequently, in the remainder of this sub-chapter, the search strategy, article selection process, coding criteria and coding process applied in the research are presented.

1.1.1 Search strategy and article selection

The present literature review focuses on the IGs provided in academic literature to move a company from its current (as-is) situation towards MC. Following the search strategy of Fogliatto, da Silveira and Borenstein (2012), the terms 'mass customization'/'mass customisation' were used in order to concentrate on papers dealing with MC. In addition, in order to focus on notions of 'implementation guidelines' or 'implementation methodology', these two search terms were combined (by using the AND operator) with at least one of the following terms (i.e. by using any of the following terms connected with the OR operator): 'implementation', 'methodology', 'mov*' (moving towards, etc.), 'enabl*' (enabler, enabling, enable, etc.), 'adopt*' (adoption, adopt, etc.), 'obstacl*' (obstacle, obstacles, etc.) or 'guid*' (guide, guidelines, etc.). The use of these keywords to search for IGs is based on the synonymous way in which the terms 'implementation guidelines' and/or 'implementation methodology' are used in the management literature dealing with implementation (cf. Ortiz, Lario, and Ros 1999, Rouhani et al. 2015).

The search was conducted on Article Title, Abstract and Keywords in the Scopus database. The search encompassed articles published up to March 2015. Conference papers, conference reviews, books and book chapters were excluded from the search. This choice follows the motivation provided by Fogliatto, da Silveira, and Borenstein (2012), who assert that the field of MC research is mature enough to allow searches for significant research contributions in articles only. Furthermore, only publications in the English language were taken into account. Using these search criteria, the initial search yielded 549 articles (Figure 2).

These 549 articles were further selected based on the quality of the journal in which they were published. SCImago database rankings were used as a measure of journal quality. A journal and its publications were taken into account only if all subject categories in which the journal was classified in the SCImago database were ranked Q1 or Q2 in the SCImago rankings for the year 2013. This criterion led to a total of 387 articles published in 145 journals.

A number of these 387 articles are not really intended to guide MC implementation in practice. For example, some of them are review articles, some deal with MC enabler typologies, etc. Thus, the following set of criteria was developed to further refine my selections:

Criterion 1. Article states the objective of developing MC-IGs or claims to contribute to guiding the implementation of MC

Criterion 2. Article provides information about the order in which two or more MC enablers should be implemented

Criterion 3. Article provides implementation instructions for each of two or more MC enablers, regardless of whether or not it fulfils Criterion 2

Once these criteria were established, the abstracts were read and criterion 1 applied to exclude articles that were clearly not intended to guide MC implementation in practice. When there was doubt about whether an article fit the selection criteria, it was left for the next selection step. In this way, a conservative approach was applied in the selection process, which meant that criterion 1 had to be applied in the next step – reading the texts in full – as well. This led to 235 articles.

Some of the 235 articles deal with several MC enablers, while others deal with only one MC enabler. Mass customization enablers are technology- and organization-based factors that support the development of MC capabilities (Hart 1995; Da Silveira, Borenstein, and Fogliatto 2001). Although there are numerous articles covering single MC enablers, these do not directly add to MC-IGs. Mass customization implementation guidelines should consider multiple MC enablers, since the MC literature shows that MC is a result of more than one MC enabler (Da Silveira, Borenstein, and Fogliatto 2001; Ma, Wang, and Liu 2002; Salvador, Forza, and Rungtusanatham 2002; Hernandez, Allen, and Mistree 2003; Piller, Moeslein, and Stotko 2004; Blecker and Abdelkafi 2006; Krishnapillai and Zeid 2006; Q. H. Yang et al. 2007; Shamsuzzoha, Kyllönen and Helo 2009; Daaboul, Bernard and Laroche 2012; Fogliatto, da Silveira, and Borenstein 2012; Purohit et al. 2016) and that there is a need for a holistic approach to MC implementation (Feitzinger and Lee 1997; Jiao, Zhang, and Pokharel 2005; Q. H. Yang et al. 2007; Daaboul, Bernard, and Laroche 2012; Bednar and Modrak 2014). Consequently, the further article selection was based on the shared belief that two or more MC enablers should be implemented in order to achieve MC. This is the rationale underlying criteria 2 and 3. Using these criteria in combination with criterion 1, through full text reading, the further selection was narrowed to 20 articles. Figure 2 shows the overview of the article search and selection process.

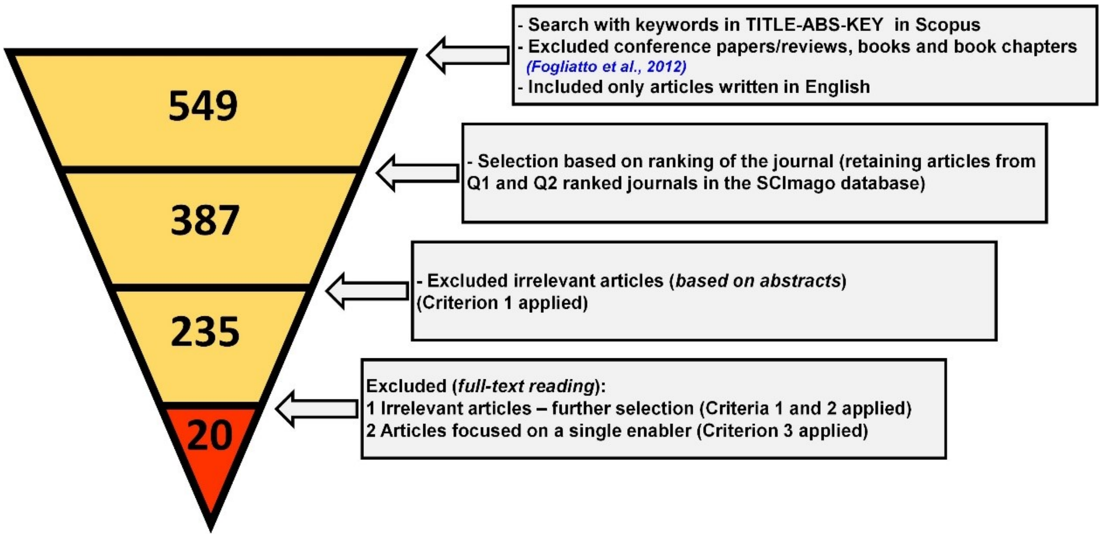


Figure 2. Article search and selection steps

These 20 articles are distributed among 17 journals (Table 1). This small number of articles and the fact that half of them were published in the last five years (since 2010) suggest that MC-IG research can be considered a small but emerging substream of MC research. Table 1 also shows the high dispersion of articles among journals and the prevalence of engineering and industrial engineering journals among the sources.

Table 1. Journal overview with articles

Journal name	No. of relevant articles per journal	Article/s
International Journal of Computer Integrated Manufacturing	3	Yang, Q. H., Qi, Lu and Gu (2007) Gao, Zhang, and Xiao (2013) Hanafy and ElMaraghy (2015)
Open Construction & Building Technology Journal	2	Kudsk, Grønvold, Olsen, Hvam, and Thuesen (2013) Kudsk, Hvam, Thuesen, Grønvold, and Olsen (2013)
AI EDAM: Artificial Intelligence for Engineering Design, Analysis and Manufacturing	1	Zha, Sriram, and Lu (2004)
Business Horizons	1	Salvador, Forza, and Rungtusanatham (2002b)
Concurrent Engineering: Research and Applications	1	Kong, Ming, L. Wang, X. H. Wang, and P. P. Wang (2009)
Engineering Optimization	1	Hernandez, Allen, and Mistree (2003)
IEEE Transactions on Engineering Management	1	Ismail, Reid, Mooney, Poolton, and Arokiam (2007)

IIE Transactions (Institute of Industrial Engineers)	1	Moon, Shu, Simpson, and Kumara (2010)
International Journal of Production Research	1	Qu, Bin, Huang, and H. D. Yang (2011)
International Journal on Interactive Design and Manufacturing	1	Bajaras and Agard (2014)
Journal of Intelligent Manufacturing	1	Jiao and Tseng (1999)
Journal of Mechanical Design	1	Moon and McAdams (2012)
Journal of Mechanical Engineering - Strojniski vestnik	1	Anišić and Krsmanović (2008)
Journal of Systems and Software	1	Alsawalqah, Kang, and Lee (2014)
Management Decision	1	Blecker and Abdelkafi (2006)
Research in Engineering Design	1	Gao, Xiao, and Simpson (2009)
The International Journal of Advanced Manufacturing Technology	1	Meng, Jiang, and Huang (2006)
Total	20	

1.1.2 Coding process and coding criteria

'At one extreme the codes can be taken from theory or at the other extreme derived from the data' (Åhlström and Karlsson 2008, 218). Unfortunately, a research framework suitable to guide a deductive analysis of the articles was not found. Accordingly, the classification scheme was built in an inductive manner (Thomas 2006). Inductive analysis 'refers to approaches that primarily use detailed readings of raw data to derive concepts, themes, or a model through interpretations made from the raw data by an evaluator or researcher' with a primary purpose 'to allow research findings to emerge from the frequent, dominant, or significant themes inherent in raw data, without the restraints imposed by structured methodologies' (Thomas 2006, 238). This absence of preconception in the analysis of scientific contributions is one of the reasons why in recent years inductive analysis has been gaining significance as a data analysis strategy in systematic literature reviews (Weiskopf and Weng 2013; Couture et al. 2015; Harvey et al. 2015; Thuan, Antunes, and Johnstone 2015; Wood and Mckelvie 2015).

The inductive coding process consisted of five phases (Table 2), during which, articles were read several times in order to identify themes and categories (coding dimensions and codes). After the initial identification of specific relevant text segments (phases 1 and 2, Table 2), text segments were labeled and a provisional classification scheme was created and applied to the articles (phase 3). Next, the tentative scheme was iteratively refined based on group discussions, and the articles were re-classified (phase 4, Table 2). This iterative process continued until complete agreement was reached among the PhD candidate, the supervisor and the two co-supervisors. After the final classification of the articles, the MC-IG building blocks were identified by marking out the subset of coding dimensions that directly address the content of MC-IGs (phase 5, Table 2).

Table 2. The steps of the inductive analysis coding process (based on Creswell 2002, Thomas 2006)

Phase number	Phases of the inductive analysis coding process (Thomas 2006, based on Creswell 2002)	Description of the coding phase	Resulting number of categories
1	Initial reading of text data	Initial reading of the relevant articles (done in the selection process)	Categories not yet defined
2	Identify specific text segments related to objectives	Initial identification of text segments dealing with MC-IGs	Multiple potential categories
3	Label the segments of text to create categories	Creation and application of a tentative classification scheme	123
4	Reduce overlap and redundancy among categories	Iterative refinement of the tentative classification scheme through discussion in research team	61 (17 coding dimensions/sub-dimensions and 44 codes/sub-codes)
5	Create a model incorporating the most important categories	Deriving of MC-IG building blocks by marking out the subset of coding dimensions that directly address the content of MC-IGs	7 (MC-IG building blocks)

In order to make the inductive approach more transparent, hereafter more details on part of the process are provided. More specifically, the identification of the coding dimension and codes for the 'applicability context of the guidelines' is presented (Table 3). The applicability context of the guidelines (dim. 2, Table 3) is reported in a number of articles, but in some articles the applicability context is stated and its validity is backed up (justified) by a clear explanation (dim. 2–code 1, Table 3), while other articles simply state the applicability context without explaining why this context is valid for the presented MC-IGs (dim. 2–code 2, Table 3). Further, some articles simply presume that the applicability context is self-evident, since, for example, all of the examples the article provides are related to one industry or product type (dim. 2–code 3, Table 3). In the end, some articles did not provide even a hint of the applicability context (dim. 2–code 4, Table 3). In order to avoid redundancy, coding dimensions as well as their codes will be defined and further explained in the Results section of this chapter.

Table 3. Coding dimensions with codes

Dim./sub-dimension number	Coding dimension/sub-dimension name	Codes/sub-codes
1	MC overview	1) MC overview provided 2) MC overview not provided
2	Applicability context of the guidelines	1) Applicability context specified and justified 2) Applicability context specified 3) Applicability context not explicitly specified but self-evident 4) Applicability context not explicitly specified and not self-evident
3	Required resources	1) Required resources addressed 2) Required resources not addressed
4	As-is analysis tools	1) As-is analysis tools provided 2) As-is analysis tools not provided
5	Hindrance factors	1) Hindrance factors provided 2) Hindrance factors not provided
6	Instruction contents	
6.1	*'Single enabler' implementation instructions*	1) 'Single enabler' implementation instructions provided[a] 2) 'Single enabler' implementation instructions not provided[a] [a] This coding is specified for each of the enablers
6.2	*'Bundled enabler' implementation instructions*	
6.2.1	*Inclusion of enablers in 'bundled enabler' implementation instructions*	1) 'Bundled enabler' implementation instructions provided[b] 2) 'Bundled enabler' implementation instructions not provided[b] [b] This coding is specified for each of the enablers
6.2.2	*Relationships between enablers included in 'bundled enabler' implementation instructions*	1) Precedence relationship[c] 2) Embedding relationship[c] 3) Parallel implementation[c] 4) No relationship provided between enablers[c] [c] This coding is specified for each pair of enablers
7	Instruction exemplification	1) Exemplified implementation instructions 2) Non-exemplified implementation instructions
7.1	*Exemplified implementation instructions purpose*	1) Explaining how the enabler should work when applied in practice (a) 2) Example of implementation instructions application in practice (b) 3) Examples used for both purposes (a+b)
8	Instruction format	1) Textual format—with two possible values: 1.1) Plain text only 1.2) Organized text 2) Graphical format 3) Tabular format

continuing Table .3 Coding dimensions with codes

9 *9.1*	Research method *Research method to build the implementation guidelines*	1) Conceptual modeling 2) Case studies 3) Surveys 4) Mathematical modeling 5) Action research
9.2	*Research method to assess the validity of the implementation guidelines*	1) Conceptual modeling 2) Case studies 3) Surveys 4) Mathematical modeling 5) Action research 6) Not tested
10	Knowledge origin	1) Knowledge sourced from academia 2) Knowledge sourced from practice 3) Knowledge sourced from academia and knowledge sourced from practice

1.2 Results of the MC implementation guidelines literature review

The 20 selected articles were analyzed carefully via full-text reading and were classified based on (1) MC overview, (2) applicability context of the guidelines, (3) required resources, (4) as-is analysis tools, (5) hindrance factors, (6) instruction contents, (7) instruction exemplification, (8) instruction format, (9) research method and (10) knowledge origin.

1.2.1 Mass customization overview

A *mass customization overview* is a presentation of the essentials of the MC concept. These essentials include a definition of MC, a list of MC enablers, definitions of MC enablers, a set of the basic MC enabler relationships, a list of the company departments involved in implementing MC, a set of the benefits derived from MC implementation and a set of the benefits derived from each MC enabler implementation. The MC definition and the list of MC enablers together compose a minimum MC overview: These provide practitioners with an understanding of what MC is and what could be done to become a mass customizer so they can approach the process in a comprehensive way, thus avoiding a piecemeal approach and possible misunderstandings of the MC concept.

Mass customization is a wide and still developing research field that requires substantial effort to grasp. An MC overview reduces the efforts required by a practitioner to acquire basic knowledge of MC by concisely presenting the essence of MC.

According to the MC overview classification dimension, relevant papers are classified as follows (Table 4):

1. MC overview provided – a case when at least a simple MC overview is presented in the paper. An example of a simple MC overview is one that contains a definition of MC and a list of MC enablers.
2. MC overview not provided – a case when an overview of the MC concept is not presented in the paper. For example, a definition of MC is provided in the paper, but other components, such as a list of MC enablers, definitions of MC enablers, etc., are not present in the paper.

Table 4. Summary of the articles, classified according to MC overview

Coding dimension	Codes	Number of articles	Percent of articles
MC overview	MC overview provided	4	20%
	MC overview not provided	16	80%
	Total number of articles	20	100%

Only a few articles (20%, Table 4) provide an overview of MC. These articles differ substantially regarding the MC overviews they provide. Either they cover a wide range of MC overview components (e.g. Jiao and Tseng 1999; Q. H. Yang et al. 2007) or the researchers focus their work on the article's scope, addressing only a few MC overview components.

Although the majority of articles do not provide an overview of MC, most of them do provide certain MC overview components, such as a definition of MC (65%) or some definitions of MC enablers (90%), and so on. When articles do provide a definition of MC, most of them (54%) refer to Pine II (1993). Meanwhile, the number of MC enabler definitions provided in the articles varies according to the number of enablers they address, and these definitions are usually limited to the MC enablers that fall within the article's scope.

1.2.2 Applicability context of the guidelines

Applicability context of the guidelines concerns the generalizability of the MC implementation guidelines. The applicability context provides the limits of validity for the proposed guidelines. For example, the industry, types of products, size of the company, and so on, represent the applicability context of the guidelines.

The applicability context helps practitioners understand whether the implementation guidelines are applicable to their case. This is true even when the applicability context is simply specified without any further elaboration. Specification of the applicability context implies that the researchers have thought about the generalizability of the guidelines instead of leaving this thinking solely to practitioners.

According to the applicability context relevant papers are classified as (Table 5):

1. Applicability context specified and justified – A case when applicability context is stated accompanied by justification. Example is the case when it is stated that implementation guidelines are applicable in building construction industry followed by justification of why this is so.
2. Applicability context specified – A case when applicability context is provided but is not accompanied by justification. For example, it is stated that implementation guidelines are applicable in service industry, but without justification of why this is so.
3. Applicability context not explicitly specified but self-evident – A case when applicability context is not addressed in the guidelines, but either way it is self-evident. Example is providing products examples through the whole paper, which makes it evident that applicability context is manufacturing and not the services sector.

4. Applicability context not explicitly specified and not self-evident – A case when applicability context is not addressed in the guidelines. For example, guidelines are provided, but without explicitly or implicitly providing the industry they are applicable to.

Table 5. Summary of the articles classified according to applicability context of the guidelines

Coding dimension	Codes	Number of articles	Percent of articles
Applicability context of the guidelines	Applicability context specified and justified	2	10%
	Applicability context specified	5	25%
	Applicability context not explicitly specified but self-evident	12	60%
	Applicability context not explicitly specified and not self-evident	1	5%
	Total number of articles	20	100%

The applicability context dimension was explicitly covered in 35% (first two codes in Table 5) of the articles, which shows that generalizability tends not to be justified openly in the articles. Only two articles that address the generalizability issue were found. Kudsk, Hvam et al. (2013) indicate generalizability by stressing similarities between the building construction industry and the cement factory design/construction sector. Ismail et al. (2007, 86) limited the applicability context of their guidelines to small and medium enterprises (SMEs) because 'the resources required to implement such a strategy [mass customization] in an SME often falls beyond what is considered to be acceptable risk'. While Kudsk, Hvam et al. (2013) generalized applicability starting from successful MC application, Ismail et al. (2007) based their applicability context on a widely recognized characteristic of SMEs: the lack of resources.

Most of the articles deal with manufacturing (90%), and only 5% of articles deal with services. The articles that deal with manufacturing mostly address mechanical production, electronics and construction. These articles address complex products such as cars, industrial steam turbines, computers, etc. Country and market are not addressed as applicability contexts in the articles.

1.2.3 Required resources

Required resources are the resources needed to implement MC or one or more MC enablers. Some examples of required resources are the financial resources, the time, the human resources, and so on, required for MC implementation.

Required resources provide practitioners the possibility to estimate the resources that are needed for MC implementation. Even rough data about the required resources can be of high value to practitioners and can be used as a reference point.

According to the resources required, relevant papers are classified as (Table 6):

1. Required resources addressed – A case when resources needed to implement MC are stated. Example of required resources for MC implementation are financial resources needed for product platform development in one's company.
2. Required resources not addressed – A case when resources needed to implement MC are not stated. For example, implementation instructions for product platform development and product modularization can be provided, but without stating time, financial or human resources that are needed in order to reach this implementation.

Table 6. Summary of the articles classified according to required resources

Coding dimension	Codes	Number of articles	Percent of articles
Required resources	Required resources addressed	4	20%
	Required resources not addressed	16	80%
	Total number of articles	20	100%

Besides being addressed in a relatively small percentage of the articles (20%, Table 6), the resources required to implement MC are also addressed in a relatively superficial way. Furthermore, when they are addressed, most of the time only a single resource is addressed per article. The types of resources addressed are financial resources, human resources and generic resources (e.g. 'efforts', a term used to signal the amount of overall resources needed without specifying them). The financial resources required to implement MC are often represented indirectly in the literature through different costs. Kudsk, Hvam et al. (2013, 96) refer to the cost of a product configurator through an estimated 'cost of the software' based on prior experiences in MC implementation; Moon and McAdams (2012, 5) introduce 'additional costs for developing a new platform', while Hanafy and ElMaraghy (2015, 1003) point to the 'Cost of labour training to assemble a certain platform type' that is incurred in the development of a product platform. The human resources for developing a configuration system are addressed by Kudsk, Hvam et al. (2013, 96) with exact numbers: 'it was deemed necessary to use four man years to develop the system'. Finally, sometimes resources are not specified but are considered in a generic way. Alsawalqah, Kang and Lee (2014, 104) use generic terms, referring to the 'significant efforts' needed for optimizing a software product platform.

It should also be noted that the set of required resources is usually limited to the scope of the article, and includes, at the most, those resources required for implementing the one or two MC enablers considered in the article, usually not taking into account the overall implementation of MC.

1.2.4 As-is analysis tools

As-is analysis tools support assessments of the current company situation with respect to future MC implementation challenges. They can be in the form of procedures, formulae, templates, and so on.

The starting situations of companies usually differ substantially depending on industry, size, human resources, etc. As-is analysis tools provide a way to respect these differences when making decisions about future MC implementation activities.

According to the as-is analysis tools, relevant papers are classified as (Table 7):

1. As-is analysis tools provided – A case when tools to support an assessment of the current company situation are provided. An example of the as-is analysis tool is a set of formulae to measure the current level of similarity among parts within product families.
2. As-is analysis tools not provided – A case when tools to support an assessment of the current company situation are not provided. An example is when guidelines do not take the current company situation into account.

Table 7. Summary of the articles classified according to as-is analysis tools

Coding dimension	Codes	Number of articles	Percent of articles
As-is analysis tools	As-is analysis tools provided	5	25%
	As-is analysis tools not provided	15	75%
	Total number of articles	20	100%

When included in the article (25% of the articles, Table 7), as-is analysis tools do not go beyond the scope of the MC enablers addressed in the article. So, when proposing a methodology for the development of product family architecture for MC, Jiao and Tseng (1999, 9) group customers by using an analysis where 'different sets of FR [functional requirement] variables are formulated for various customer groups' and 'in which similarities of customer's needs, i.e. FRs instances, are evaluated'. In this way, Jiao and Tseng (1999) use their as-is analysis tool for a specific part of the implementation of one MC enabler. Further, a tool called the Product Variant Master (PVM) is applied in two articles (Kudsk, Grønvold et al. 2013; Kudsk, Hvam et al. 2013) 'in order to analyze the case company and its product range' (Kudsk, Hvam et al. 2013, 90). In these two cases, as-is analysis using the PVM is done in order to enable successful implementation of yet another MC enabler: IT-based product configuration. An as-is analysis tool is also proposed in Salvador, Forza and Rungtusanatham (2002b), where assessment of an as-is situation is carried out through a 'mass customization roadmap', which proposes a company analysis based on the customization level and product modularity type. Finally, Ismail et al. (2007) conduct an as-is analysis that applies product similarity measures to existing product families.

1.2.5 Hindrance factors

Hindrance factors are variables that negatively affect MC implementation. They can appear in the form of resistance to change as well as various other obstacles, challenges, barriers, and so on.

Hindrance factors are important for practitioners because they provide additional knowledge for MC implementation. While it is important to know what to implement and how to implement it, it is also highly important to be aware of the variables that can slow/stop the implementation process. Knowing the hindrance factors could help to successfully counter their effects.

According to hindrance factors, relevant papers are classified as (Table 8):

1. Hindrance factors provided – A case when guidelines provide variables that negatively affect MC implementation. An example of a hindrance factor is the resistance to change that can appear in managers and employees towards the change process and implementation of new practices in everyday work.
2. Hindrance factors not provided – A case where guidelines do not provide variables that negatively affect MC implementation. An example is providing detailed implementation instructions for product platform development and parts standardization, but without stating which factors could hinder this implementation.

Table 8. Summary of the articles classified according to hindrance factors

Coding dimension	Codes	Number of articles	Percent of articles
Hindrance factors	Hindrance factors provided	3	15%
	Hindrance factors not provided	17	85%
	Total number of articles	20	100%

Hindrance factors receive limited attention in the articles (15%, Table 8). However, some articles do provide insights on factors that could hinder MC implementation. Kudsk, Hvam et al. (2013, 98) find hindrance factors in the form of resistance to change from managers and company engineers, underlining that 'Generally, the professionals were positive towards the idea and very helpful when they gained an understanding of the project, but often the areas where they saw potential were not the areas they worked with themselves'. Not admitting to seeing potential for improvement in their own field of influence is a way for managers and engineers to resist the pressure to change. Ismail et al. (2007, 95) argue that MC implementation in SMEs could be hindered by lack of resources, stating that 'The monitoring of the implementation process would seem to be critical as SME are unlikely to possess the resources and capacity to achieve everything on their own'. Ismail et al. (2007, 95) continue, stating that 'SMEs generally lack the internal costing structures that enable them to clearly quantify the benefits of product rationalization or MC', which may further hinder MC implementation efforts. Hanafy and ElMaraghy (2015, 1008) point out that implementation of product platforms may be hindered by a need for employee training: 'Platform labour training is used to capture additional costs associated with each platform and it penalises excessive use of platforms'.

1.2.6 Instruction contents

The Merriam-Webster online dictionary defines instruction as:

(1) 'a statement that describes how to do something' or
(2) 'the action or process of teaching: the act of instructing someone'[1]

For the purposes of this research, we use the first Merriam-Webster definition and define *implementation instructions* as: anything that describes how to do something. In our case, this 'doing something' reads 'implementing MC'.

Instruction contents define the scope of the provided implementation instructions. Implementation instructions can include one or more than one enabler and can differ substantially depending on their scope. Instruction contents can include:

(1) 'Single enabler' implementation instructions
(2) 'Bundled enabler' implementation instructions

Instruction contents are important for practitioners because the scope of the enablers the implementation guidelines cover impacts the applicability of those guidelines. Thus, we can expect that a decision about whether to use the implementation guidelines will be impacted by the practitioner's perception of whether or not the scope of the implementation guidelines is suitable.

The enablers considered in the implementation instructions. A number of enablers are considered in the 'single enabler' implementation instructions and/or the 'bundled enabler' implementation instructions in the articles. For the sake of clarity, these enablers, their definitions and the main advantages they bring when they are implemented are listed in the Appendix.

'Single enabler' implementation instructions are instructions that are presented in a way that renders them usable as guidance to implement one specific MC enabler in practice.

'Single enabler' implementation instructions are crucial for practitioners because they save the time and effort required for identifying and elaborating the various enabler implementation steps. They also make accumulated and validated knowledge operationally available (actionable) to practitioners.

[1] http://www.merriam-webster.com/dictionary/instruction

According to single enabler implementation instructions relevant papers are classified as (Table 9):

1. Single enabler implementation instructions provided – A case when detailed implementation instructions are provided for a specific enabler. For instance 'in order to modularize product portfolio all components should be identified, clustering of components into modules should be done, interfaces between modules defined…' is an example of the single enabler implementation instructions.
2. Single enabler implementation instructions not provided – A case when detailed implementation instructions are not provided for a specific enabler. For instance without containing detailed implementation instructions for any of considered enablers, paper could still provide multiple enabler interdependence implementation instructions for some of the enablers.

The number of enablers for which 'single enabler' implementation instructions are provided varies considerably across articles (Table 9). But, in most cases (75% of articles), these instructions are provided for two or three enablers per article.

Table 9. Summary of the articles classified according to 'single enabler' implementation instructions

Coding dimension	Codes	Count per article	Number of articles	Percent of articles
'Single enabler' implementation instructions	'Single enabler' implementation instructions provided for…	6 or more enablers	0	0%
		5 enablers	1	5%
		4 enablers	1	5%
		3 enablers	6	30%
		2 enablers	9	45%
		1 enabler	2	10%
	'Single enabler' implementation instructions not provided	…not provided	1	5%
		Total number of articles	20	100%

In order to better understand which enablers are crucial for MC implementation, first a list of MC enablers for which at least one article provides 'single enabler' implementation instructions was made. Subsequently, the percentage of articles that provide 'single enabler' implementation instructions for each enabler on this list was calculated (Table 10).

Table 10. List of used enablers in the articles, with frequency of appearance (based on 'single enabler' implementation instructions provided)

Enabler name	Number of articles in which 'single enabler' implementation instructions are provided	Percent of articles in which 'single enabler' implementation instructions are provided
Product platform development	14	70%
Product modularization	14	70%
Part standardization	7	35%
IT-based product configuration	6	30%
Group technology	3	15%
Form postponement	2	10%
Sourcing configuration for MC	1	5%

There are 7 enablers for which 'single enabler' implementation instructions are provided in the articles (Table 10). The most frequently considered enablers are product platform development and product modularization, for which 'single enabler' implementation instructions are provided in 14 articles. Part standardization and IT-based product configuration are present in 6 or 7 articles. The least considered enablers are group technology (3 articles), form postponement (2 articles) and sourcing configuration for MC (1 article).

'Single enabler' implementation instructions may or may not include the sequence of activities. The sequence of activities is the constraint-driven order of the activities needed to implement one MC enabler. In order to be treated as a sequence, at least one constraint must be explicitly stated between the start and finish of the different MC implementation activities. An analysis of the articles that include 'single enabler' implementation instructions shows that 43% of the cases provided the sequence of activities to be done during the enabler implementation.

'Bundled enabler' implementation instructions are implementation instructions that define relationships between two or more enablers. The relationship can be one of precedence, embedding or parallel implementation. While 'single enabler' implementation instructions aim to provide detailed implementation instructions for one specific enabler, 'bundled enabler' implementation instructions aim to define the relationships between two or more enablers.

'Bundled enabler' implementation instructions are important for practitioners because they reduce the efforts required for MC implementation planning. Thus, practitioners can incorporate these instructions as they appear in their MC implementation plans or they can implement them with some modifications.

According to multiple enabler interdependence implementation instructions relevant papers are classified as (Table 11):

1. 'Bundled enabler' implementation instructions provided – A case when relationship between two or more enablers are defined. For instance instructions can state that part standardization must precede product modularization in the implementation process.
2. 'Bundled enabler' implementation instructions not provided – A case when no relationships between the enablers are defined. In this case paper can provide single enabler implementation instructions for enabler A and enabler B but without relating these two enablers in any way.

Table 11. Summary of the articles classified according to inclusion of enablers in 'bundled enabler' implementation instructions

Coding sub-dimension	Codes	Count per article	Way of presenting the relationships in the article			No. of articles (percent)
			E*	I	E/I	
Inclusion of enablers in 'bundled enabler' implementation instructions	'Bundled enabler' implementation instructions provided	6 related enablers	1	0	0	1 (5%)
		5 related enablers	0	1	1	2 (10%)
		4 related enablers	0	0	0	0 (0%)
		3 related enablers	6	2	1	9 (45%)
		2 related enablers	7	1	0	8 (40%)
	'Bundled enabler' implementation instructions not provided	No related enablers	N **	N	N	0 (0%)
		Total number of articles	14	4	2	20 (100%)

** E – explicit; I –implicit; E/I – in part explicit and in part implicit; ** N – not applicable*

'Bundled enabler' implementation instructions are provided in all 20 articles (Table 11). Please note that the selection criteria allowed the retention of articles that do not explicitly provide 'bundled enabler' implementation instructions. However, a very careful reading of these articles revealed the presence of implicit 'bundled enabler' implementation instructions. For this reason, instructions were categorized not only according to the number of enablers participating in the relationship, but also according to the degree of explicitness (explicit, implicit, in part explicit and in part implicit) of the presentation of the relationships among the implementations of different enablers. The result is that most 'bundled enabler' implementation instructions are provided for three enablers (9 articles) or two enablers (8 articles) and are explicitly provided in 14 (70%) articles (Table 11).

‘Bundled enabler’ implementation instructions can refer to different relationships between enablers. Thus, alternative relationships could be one of the following:

(1) Precedence relationship – A case when implementation guidelines state that one enabler should be implemented before the other enabler. For example, instructions can state that part standardization must precede product modularization in the implementation process. According to a precedence relationship, one enabler should be sequenced before or after another enabler.
(2) Embedding relationship – A case when implementation guidelines state that one enabler is a part of another enabler’s implementation. For example, implementation guidelines could indicate that product modularization is not an independent enabler but is a part of product platform development. In this case, the product modularization enabler is embedded in the product platform development enabler.
(3) Parallel implementation – A case when implementation guidelines state that one enabler should be implemented at the same time as another enabler. For example, instructions can state that form postponement should be implemented at the same time as product platforms are developed.
(4) No relationship provided between enablers – A case when implementation guidelines do not indicate a relationship between two enablers. For example, ‘single enabler’ implementation instructions for IT-based product configuration and for form postponement are provided in the article, but these two enablers are not related in any way.

A detailed analysis of enabler relationships is provided in Table 12. In order to understand how to read Table 12, let us consider four cells focused on product platform development [PP,PP] and product modularization [M,M] as well as their relationship [PP,M], [M,PP]. We can see that 16 articles deal with product platform development [PP,PP] = 16, while 15 articles consider product modularization [M,M] = 15. It must be noted that ‘[PP,PP] = 16’ and ‘[M,M] = 15’ are numbers that represent the instances when an enabler is covered in the article in either ‘single enabler’ implementation instructions or in ‘bundled enabler’ implementation instructions, or in both. These numbers are slightly higher than those recorded in Table 10 (which are 14 for PP and 14 for M) because Table 10 provides an overview of the articles that takes into account only ‘single enabler’ implementation instructions. Only 13 articles provide a relationship between product platform development and product modularization ([M,PP] = 13). Further, from cell [PP,M], we can see that of these 13 articles, 11 articles say that row PP is embedding column M (E = 11); 1 article says that PP is sequenced after M (A = 1); and 1 article says that PP is embedded in M (M = 1).

Table 12. MC enabler relationships recorded in the articles

	PP	M	PC	S	GT	P	PM	SC
PP	16	B - A 1 E 11 M 1 P - NS -	B 6 A - E - M - P - NS -	B - A 1 E 6 M - P - NS -	B - A 1 E - M - P 1 NS -	B 1 A 1 E - M - P 1 NS 1	B - A 1 E - M - P - NS -	B - A - E - M - P - NS -
M	13	15	B 6 A - E 1 M - P - NS -	B - A 2 E 1 M - P 1 NS 1	B - A 2 E - M - P - NS -	B 1 A - E 1 M 1 P - NS -	B 1 A - E - M - P - NS -	B - A - E - M - P 1 NS -
PC	6	7	9	B - A 3 E - M - P - NS -	B - A 2 E 1 M - P - NS -	B - A 1 E - M - P - NS 1	B - A - E - M - P - NS -	B - A - E - M - P - NS -
S	7	4	3	8	B - A 1 E - M 1 P - NS -	B 1 A 1 E - M 1 P - NS -	B 1 A - E - M - P - NS -	B - A - E - M - P - NS -
GT	2	2	3	2	5	B 1 A - E - M - P 1 NS -	B 1 A - E - M - P - NS -	B - A - E - M - P - NS -
P	3	3	1	3	2	4	B - A 1 E - M - P - NS -	B - A - E - M - P - NS -
PM	1	1	-	1	1	1	1	B - A - E - M - P - NS -
SC	-	1	-	-	-	-	-	1

Table acronyms – Enablers: PP – Product platform development; M – Product modularization; PC – IT-based product configuration; S – Part standardization; GT – Group technology; P – Form postponement; PM – Process modularity; SC – Sourcing configurations for MC

Relationships between enablers (where X is an enabler in the table row, Y is an enabler in the table column): B - X is sequenced before Y; A - X is sequenced after Y; E - X is embedding Y; M - X is embedded by Y; P - X and Y are implemented in parallel; NS – relationship between X and Y not specified, although they both appear in the article

Table 12 shows that the relationships between enablers have been frequently studied for some enabler pairs (e.g. [M,PP] = 13), rarely studied for other pairs (e.g. [P,PC] = 1) and not studied at all for some pairs (e.g. [SC,PC] = 0). In order to determine whether there is agreement on the relationships between an enabler pair, we needed at least two articles that investigate that relationship. Fortunately, the possible mutual pairings (10 enabler pairs) for five enablers have been studied in at least two articles. These five enablers are product platform development (PP), product modularization (M), IT-based product configuration (PC), part standardization (S) and group technology (GT). Incidentally, these are the enablers that appear most frequently in the 'single enabler' and 'bundled enabler' implementation instructions ([PP,PP] = 16, [M,M] = 15, [PC,PC] = 9, [S,S] = 8 and [GT,GT] = 5). In general, there is agreement regarding the relationship between these five enablers (Table 12). There is also agreement that PP embeds M; PP is sequenced before PC, and so on; and there is agreement that group technology is the first enabler to be introduced, followed by product platform development and ending the MC implementation with IT-based product configuration. The articles also agree that product platform development embeds part standardization and product modularization, which are further sequenced in order of mention. In summary, there is agreement on a linearized enabler relationship model, which is depicted in Figure 3.

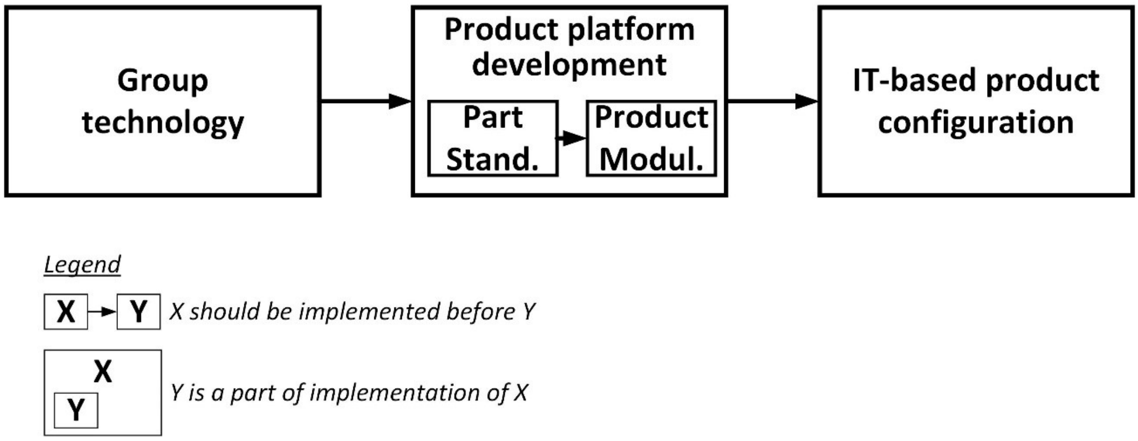


Figure 3. Linearized model of basic enabler relationships derived from the analysis of articles

For the remaining three enablers (P, PM and SC), no clear agreement emerges. For PM and SC, this is because they are considered only once in all articles (Table 12). For P, the recorded relationships with other enablers are contradictory (Table 12), leading to a lack of a dominant type of relationship.

1.2.7 Instruction exemplification

Instruction exemplification refers to providing an example of an implementation instruction's application. The aim of the example is to show how an application of the implementation instruction would look in practice.

Instruction exemplification is important for practitioners because it reduces the efforts needed to understand the instructions. Exemplifications allow practitioners to compare the results of an implementation with his/her own experience. In this way, the practitioner does not need to come up with an example, which reduces the effort needed to correctly figure out how an instruction can be applied in a specific context. According to the presence of example implementation instructions are classified as (Table 13):

1. Exemplified implementation instructions – A case when example of implementation instructions application is provided. For instance, a figure that shows a real case of a modularized product presents exemplified implementation instructions.

2. Non-exemplified implementation instructions – A case when example of implementation instructions application is not provided. For instance, group technology instructions can be provided without any examples of group technology application.

Table 13. Summary of the articles classified according to instruction exemplification

Coding dimension	Codes	Number of articles	Percent of articles
Instruction exemplification	Exemplified implementation instructions	18	90%
	Non-exemplified implementation instructions	2	10%
	Total number of articles	20	100%

Almost all articles exemplify the implementation instructions they provide (Table 13). Actually, as reader, I appreciated these examples. They helped me considerably in understanding the articles.

Examples can be used either to explain how the enabler should be applied in practice or to present an application of the implementation instructions. Of course, implementation guidelines can contain both of these cases. Table 14 provides an overview of the use of examples in implementation guidelines.

Table 14. Purpose of exemplification in MC implementation guidelines

Coding sub-dimension	Sub-codes	Number of articles	Percent of articles
Exemplified implementation instructions purpose	Explaining how the enabler should work when applied in practice (a)	1	5,6%
	Example of implementation instructions application in practice (b)	2	11,1%
	Examples used for both purposes (a+b)	15	83,3%
	Total number of articles	18	100%

Based on results from Table 13 and Table 14, it can be inferred that authors considered exemplification an important part of the implementation instructions.

1.2.8 Instruction format

Instruction format refers to the way implementation instructions are organized and presented. Depending on the instruction format, implementation instructions can be more or less well organized and presented.

Instructions provided through organized text and graphical and tabular formats are significant for practitioners because they are more understandable. Compared to plain text instructions, these kinds of instructions are more organized and better presented, leaving less chance for misinterpretation. The to-do list emerges clearly in these formats.

Implementation instructions can be provided in the following formats:

(1) Textual format:
  (a) Plain text only – A case when instructions are presented in textual format without any kind of structure. An example of plain text instructions is a prescription or a story describing enabler implementation without organizing the implementation activities in any way (no subtitles, bullet points, flow charts, etc.).
  (b) Organized text – A case when instructions are organized using bullet points, paragraphs or sections, where every bullet point/paragraph/section provides instructions for one single activity. An example would be a section that is dedicated to implementing a single enabler, with subsections dedicated to one implementation activity each.

(2) Graphical format – A case when instructions are provided through a graphical presentation, for example, in the form of a flow chart, drawing, chart, diagram, etc. An example of graphical instructions would be a flow chart of the activities needed to implement one enabler. The graphical format is usually accompanied by a textual explanation, which is regarded as part of the graphical format instruction for the purposes of coding.

(3) Tabular format – A case when instructions are given in the form of a table. An example of instructions given in a table could be a comparative analysis of the level of similarity of product families before and after the part standardization implementation done on a product assortment. The tabular format is usually accompanied by a textual explanation, which is regarded as a part of tabular format instruction for the purposes of coding.

Notably, in this analysis, codes are not mutually exclusive. Thus, one implementation instruction can be provided in multiple formats, leading to a higher total than the recorded number of implementation instructions (Table 15). For example, 'single enabler' implementation instructions for implementing product modularization could be provided through organized text, in a graphical format and in a tabular format in the same implementation guidelines. All three of these instruction formats would be recorded and coded.

Table 15. Analysis of the articles according to instruction format

Coding dimension	Codes	'Single enabler' implementation instructions: No. of 'single enabler' implementation instructions provided in a specific format	'Single enabler' implementation instructions: % from total of 47 'single enabler' impl. instr.	'Bundled enabler' implementation instructions: No. of 'bundled enabler' implementation instructions provided in a specific format	'Bundled enabler' implementation instructions: % from total of 59 'bundled enabler' impl. instr.	Total
Instruction format	Plain text (Textual format)	35	74%	27	46%	62
	Organized text (Textual format)	23	49%	27	46%	50
	Graphical format	42	89%	28	47%	70
	Tabular format	31	66%	0	0%	31
Total number of cases in which instructions have been provided		47	100%	59	100%	106
Average number of instruction formats used per instruction		2,8	-	1,4	-	N/A

'Single enabler' implementation instructions tend to provide a larger amount of information per instruction because they tend to be more detailed and elaborated, while 'bundled enabler' implementation instructions are often provided in a very brief form with much less information. Consequently, the instruction formats used for 'single enabler' implementation instructions and 'bundled enabler' implementation instructions differ considerably. While the 'single enabler' implementation instructions use 2 or 3 formats per instruction (2,8 on average), the 'bundled enabler' implementation instructions use 1 or 2 formats per instruction (1,4 on average). More specifically, for most of the 'single enabler' instructions, both plain text (present in 74% of 'single enabler' implementation instructions) and the graphical format (89%) are used, with the addition of either organized text (49%) or a tabular format (66%). The 'bundled enabler' implementation instructions use plain text (present in 46% of the 'bundled enabler' implementation instructions), organized text (46%) or a graphical format (47%), and the three couplings of these three formats are equally distributed. Notably, the tabular format is not used for 'bundled enabler' implementation instructions. Furthermore, the use of plain text and organized text is similar in both implementation instruction types, while the use of the graphical format differs. Finally, in 'single enabler' implementation instructions, the graphical format, along with the tabular format, is mainly used to provide sufficiently detailed examples of enabler implementation, while for 'bundled enabler' implementation instructions, the graphical format is most often used to convey exact relationships between enablers.

1.2.9 Research method

The *research method* is an important characteristic of a scientific contribution. This is even truer in the case of an applied discipline where the research addresses both academics and practitioners.

The research method is very important because knowing how implementation guidelines have been developed and how their validity has been assessed could help practitioners to trust them. Practitioners will see a contribution as more trustworthy if it is backed up by a case from practice.

Using the established classifications of research methods (Chen, Olhager, and Tang 2014; Pashaei and Olhager 2015) and augmenting them with the action research method (Coughlan and Coghlan 2008b), the articles have been classified as: conceptual modeling, case studies (including multiple case studies), surveys, mathematical modeling (or simulation), and action research (Table 16). This classification was used to classify:

(1) A research method to build the implementation guidelines and
(2) A research method to assess the validity of the implementation guidelines.

Table 16 shows that conceptual modeling is the main research method for building MC implementation guidelines (18 articles, 90%). At the same time, the case study is the main research method for assessing the validity of the implementation guidelines (14 articles, 70%). Interestingly, only 3 (15%) articles do not perform tests of the developed MC-IGs.

Table 16. Summary of articles according to research method (RM)

RM to assess the IGs / RM to build the IGs	Conc. model.	Case study	Survey	Math (or simul.)	Action research	Not tested	Total (percent)
Concept. modelling	0	13	0	2	0	3	18 (90%)
Case study	0	1	0	0	0	0	1 (5%)
Survey	0	0	0	0	0	0	0 (0%)
Math (or simul.)	0	0	0	0	0	0	0 (0%)
Action research	0	0	0	0	1	0	1 (5%)
Total (percent)	0 (0%)	14 (70%)	0 (0%)	2 (10%)	1 (5%)	3 (15%)	20 (100%)

A deeper analysis of the 18 articles that build IGs through conceptual modeling shows that conceptual modeling can appear as pure conceptual modeling with eventual light use of mathematics (50% of cases), or as conceptual modeling with the use of heavy mathematical reasoning (50% of cases). When applied, conceptual modeling with heavy mathematical reasoning is used either for developing optimization algorithms (78% of cases) or for developing genetic algorithms (22% of cases), both of which are always used for providing implementation instructions for product platform development and related MC enablers (e.g. product modularization, part standardization, etc.).

The 14 articles that report using case studies to assess the validity of MC-IGs, use the term *case study* in a broader sense than it is used in the field of Operations Management (see Voss, Tsikriktsis, and Frohlich 2002). While 8 articles (57% of articles) test the MC-IGs in actual contexts, 5 articles (36% of articles) simply use real company data to exemplify the application of IGs in a context similar to a real one, and 1 article (7% of articles) base their validity assessment on fake (abstract) data.

The assessment of MC-IGs through case studies can be characterized based on the number of cases used and on who performs the assessment. Most of the 14 articles that assess the validity of MC-IGs through case study use a single case study. However, three articles use multiple case studies (Ismail et al. 2007; Kudsk, Grønvold et al. 2013; Hanafy and ElMaraghy 2015). The situation is more differentiated when we consider who performs the testing in a real organization (8 of 14 articles). In this case, 50% of the articles report that testing was done by the authors themselves, while the rest of the articles (50%) do not report who did the testing of the implementation guidelines. Interestingly, none of the articles reported that the MC-IGs were tested by the company personnel with researchers involved as no more than external observers.

Only 2 articles use a method different from conceptual modeling for developing MC-IGs (Table 16). In one instance (Q. H. Yang et al. 2007), the case study method was used for building and testing implementation guidelines at the same time. Similarly, in 1 article, action research was used both to build and to assess the implementation guidelines (Kudsk, Hvam et al. 2013).

1.2.10 Knowledge origin

Knowledge origin defines the knowledge base used for the creation of implementation guidelines. Knowledge can be the result of practical experience in the field (knowledge sourced from practice), the result of academic activity in the researchers' offices using academic publications (knowledge sourced from academia) or the result of both.

Knowledge that is sourced from practice reinforces the practical applicability of implementation guidelines for practitioners. Since practitioners are interested in practical implementation, empirical evidence derived from experience makes implementation guidelines more acceptable for application.

According to the knowledge origin relevant papers can be classified as (Table 17):

1. Knowledge sourced from academia – A case when implementation guidelines are result of analytical academic thinking. Example of academic knowledge is providing implementation guidelines for product platform development, but only on the theoretical/mathematical basis, without relation to practical examples.
2. Knowledge sourced from practice – A case when implementation guidelines are result of practical experience. For example, implementation guidelines built solely upon researchers' (or other experts') practical experience with implementation of one or more enablers in company is a case of IG built on empirical evidence.
3. Knowledge sourced from academia and knowledge sourced from practice – A case when implementation guidelines are result of both analytical academic thinking and practical experience. Example are implementation guidelines built upon theoretical knowledge of IT based product configuration combined with the knowledge gained through previous experiences of MC implementation in companies that implemented product modularization on its product assortment.

Table 17. Summary of the articles classified according to knowledge origin

Coding dimension	Codes	Number of articles	Percent of articles
Knowledge origin	Knowledge sourced from academia	15	75%
	Knowledge sourced from practice	0	0%
	Knowledge sourced from academia and knowledge sourced from practice	5	25%
	Total number of articles	20	100%

The knowledge origin classification (Table 17) is closely related to the research methods (Table 16) used for building up the implementation guidelines. On the one hand, knowledge sourced from academia serves as a basis for articles that use conceptual modeling or mathematics as a research method for developing implementation guidelines. On the other hand, a combination of knowledge sourced from academia and knowledge sourced from practice is used in the articles that use case study or action research as a basis for building up implementation guidelines and, in some cases (3 times), in articles that use conceptual modeling for building up implementation guidelines.

Notably, pure knowledge sourced from practice is not used as a basis for building up MC implementation guidelines (Table 17). The reason for this could be that research focused on developing MC implementation guidelines, besides addressing MC practitioners, also addresses MC academics, which imposes the need for a solid academic grounding of the developed guidelines in order to obtain peer acceptance.

1.3 Building blocks and properties of the MC implementation guidelines

The results reported open a number of discussions. However, reflections will be constrained to two main issues: (1) MC-IG building blocks, properties and definition, and (2) opportunities to improve MC implementation guidelines.

1.3.1 MC-IG building blocks, properties and definition

Altogether, there are seven coding dimensions (Figure 4) that address the content of MC-IGs. I called these seven coding dimensions *MC-IG building blocks* (Figure 4). Thus, based on the MC-IG building blocks, I propose the following definition of MC-IGs:

Mass customization implementation guidelines (MC-IGs) are intended to guide company transformation towards MC. They do so by providing:

- An overview of MC
- The applicability context of the IGs
- As-is analysis tools to assess the current company situation
- Exemplified implementation instructions of MC enablers
- Required resources for implementation of MC enablers
- Factors that may hinder implementation of MC enablers

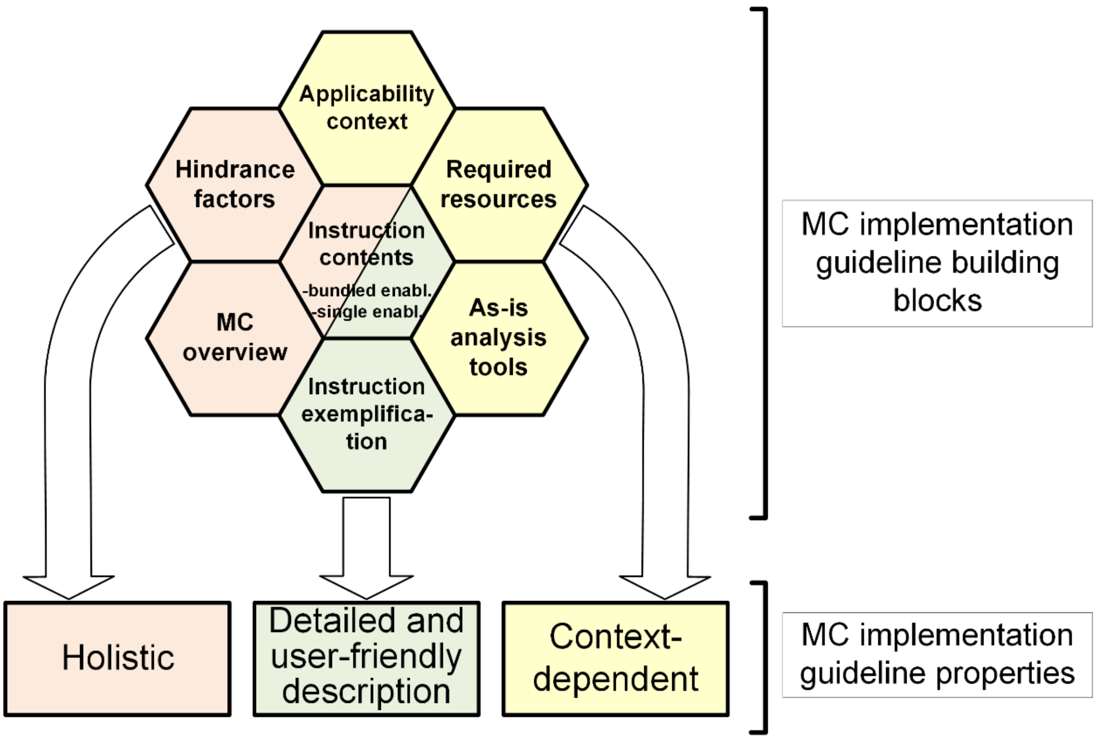


Figure 4. MC-IG building blocks and overall properties

This inductively developed definition of MC-IGs is consistent with management literature that deals with implementation guidelines/methodologies[2]. The 'MC overview' building block helps to define the company's target situation, commonly called the 'to-be situation'. This is in line with Ortiz, Lario and Ros (1999) and Rouhani et al. (2015), who call for the definition of the target (to-be) situation as a part of the implementation methodology.

The MC overview, the 'single enabler' and 'bundled enabler' implementation instructions, the hindrance factors and the required resources building blocks altogether help to plan the process of reaching the target situation. Again, this is in line with Ortiz, Lario and Ros (1999) and Rouhani et al. (2015), who call for planning the transformation from the as-is to the to-be situation.

The 'single and bundled enabler implementation instructions' building block makes IGs normative[3]. This is in line with Coughlan and Coghlan (2008a) and Rouhani et al. (2015), who call for normative implementation guidelines/methodologies and specification of the practices (enablers) to be implemented.

The 'single and bundled enabler implementation instructions' together with the 'instruction exemplification' building block, make IGs actionable. This is in line with Ortiz, Lario and Ros (1999), Coughlan and Coghlan (2008a) and Rouhani et al. (2015), who call for actionable implementation guidelines/methodologies.

The 'as-is analysis tools' building block enables the assessment of the current company situation (as-is). This is in line with Ortiz, Lario and Ros (1999) and Rouhani et al. (2015), who call for determining the as-is company situation as part of the implementation methodology.

The 'applicability context of the IGs' building block makes IGs generalizable. This is in line with Ortiz, Lario and Ros (1999), Coughlan and Coghlan (2008a) and Rouhani et al. (2015), who call for generalizable implementation guidelines/methodologies.

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[2] Ortiz, Lario and Ros (1999) and Rouhani et al. (2015) address implementation methodology in the field of enterprise architecture implementation, while Coughlan and Coghlan (2008a) address implementation guidelines for collaborative improvement in extended manufacturing enterprises.

[3] According to the Merriam-Webster Online Dictionary (http://www.merriam-webster.com/dictionary) *norms* are defined as 'standards of proper or acceptable behavior'; *normative* is defined as 'based on what is considered to be the usual or correct way of doing something'; *prescription* is defined as 'something that is suggested as a way to do something or to make something happen'; *prescriptive* is defined as 'giving exact rules, directions, or instructions about how you should do something'.

The building blocks of MC-IGs should provide a holistic, context-dependent, as well as detailed and user-friendly guide for the process of MC implementation (see Figure 4).

The *holistic guidelines* property implies the joint consideration of the various MC enablers needed to implement MC, rather than limiting the scope of MC-IGs to a single enabler. There is a call for holistic MC-IGs in the literature. Feitzinger and Lee (1997, 116) call for a 'comprehensive approach' to MC implementation, arguing that 'Instead of taking a piecemeal approach, companies must rethink and integrate the designs of their products, the processes used to make and deliver their products, and the configuration of the entire supply network'. Q. H. Yang et al. (2007, 180) argue that 'An *overall point of view* is necessary for achieving mass customization' (italics added). Sousa and Voss (2008, 706), while examining the current state of Operations Management practice contingency research, stress 'the system approach', supported by the fact that 'in the practice-performance stream a number of studies have found evidence of strong interactions between several OM practices'. Daaboul, Bernard and Laroche (2012, 2427) add to this discussion by stating that 'In the literature many methods for implementing MC are found, however none of these propose a structured way for implementing and evaluating such a *strategy as a whole*, each concentrated on one department or phase of the supply or value chains' (italics added).

The *context dependent* property refers to the need to take into account the context for which MC-IGs are intended as well as the specific situation (as-is) of every company that intends to implement MC. Thus, the context-dependent property of MC-IGs has two components:

(1) Context-specific IGs: The MC-IGs should be developed with a specific context in mind (e.g. SMEs, services, process industry, etc.). It is important to target a specific context in order to avoid a mismatch between the proposed IGs and the 'particular organizational context' (Sousa and Voss 2008, 698).
(2) IG adaptability: The MC-IGs should be adaptable to the context (external or internal) in which they are going to be applied. For example, IGs developed for a specific context (e.g. SMEs) should be adaptable to the current company situation regarding the level of implementation of each MC enabler, the available resources, the limited commitment of the personnel, etc.

There are a number of calls for context-dependent MC-IGs in the literature. Da Silveira, Borenstein and Fogliatto (2001, 11) argue that 'MC *should not be viewed as a monolithic solution*. Manufacturing processes are too complex and *context sensitive* for a single black box idea to generate flexible, agile, and focused systems' (italics added). Salvador, Forza and Rungtusanatham (2002b, 61) argue that 'differences in product complexity, product variety, production volumes, and so on may require *different firms* *to implement mass customization in different ways*' (italics added). Svensson and Barfod (2002, 88) state that 'Mass customization is not a method nor a goal, but a way of global thinking in product design, manufacturing, logistics, sales, etc. Hence, it is necessary for every company to *develop its own development plan* which will help to move in the direction towards mass customization' (italics added). Sousa and Voss (2008, 698) stress that 'Although proponents of the universal view of OM best practices would argue that implementation difficulties are part of moving the organization towards 'excellence' or 'world class status', an alternative explanation is that these difficulties result from too great a mismatch between the proposed form of best practice and the *particular organizational context*' (italics added). Salvador, De Holan and Piller (2009, 72) state that 'The trick is to remember that there is no one best way to mass customize: Managers need *to tailor the approach* in ways that make the most sense *for their specific businesses*' (italics added). McIntosh et al. (2010, 1558) state that 'Implementation has to be *tailored dependent on the specific market and business circumstances* of the company seeking a MC capability' (italics added).

The *detailed and user-friendly description* property refers to a need to provide implementation guidelines that are easily and precisely understood by the reader. Although management literature dealing with the implementation of managerial practices stresses the actionable aspect of detailed and user-friendly descriptions (Ortiz, Lario, and Ros 1999; Coughlan and Coghlan 2008a; Rouhani et al. 2015), calls for this property are not clearly recorded in the MC literature. Nevertheless, since the manager's goal is to decide what, how much and in which sequence to implement changes in the path towards MC, immediate transfer of ideas is crucial for implementation guideline usability. We argue that managers would prefer to spend the shortest time possible to grasp an idea and the actions, sequence and suitability of the implementation guidelines. After this initial acquaintance with IGs, a certain level of instruction detail, possibly exemplified, that will enable implementation of specific MC enablers is expected. If implementation guidelines are not presented in a detailed and user-friendly way, then it is likely that these guidelines will not be actionable.

1.3.2 Opportunities to improve MC implementation guidelines

1.3.2.1 Building blocks that need more attention from researchers

The results of the analysis show that MC overview, applicability context of the guidelines, required resources, as-is analysis tools and hindrance factors have received less attention in the MC-IGs available in the literature (Table 4, Table 5, Table 6, Table 7 and Table 8).

As already stated, the *MC overview* should ideally include a definition of MC, a list of MC enablers, definitions of MC enablers, a set of the basic MC enabler relationships, a list of the company departments involved in implementing MC, a set of the benefits derived from MC implementation and a set of the benefits derived from each MC enabler implementation. This information enables the practitioner to understand the main characteristics of MC and the position of MC among other manufacturing strategies (e.g. mass production, craft production, etc.) and to make a first assessment of his/her own company's position regarding MC.

Applicability context of the guidelines. The research has shown that MC-IGs could be improved by stating their applicability context, but further development of implementation guidelines will probably require that they be developed with a specific context in mind (e.g. SMEs, furniture industry, etc.). This viewpoint is further supported by Sousa and Voss (2008, 711), who state that 'the failure to acknowledge the limits of applicability of OM practices may lead to their application in contexts to which they are not suitable'. Moreover, some of the questions to be considered related to the applicability context of the guidelines are: What are the characteristics of the context that are relevant for IG development and utilization (e.g. level of product customization, industry sector, service-manufacturing distinction, company size, etc.)? Which context variables are relevant for tailoring the IGs for each case of MC implementation? Which components of the IGs are context dependent and which are not? In addition, the maturity level of the MC implementation could be considered as a specific aspect of the applicability context that could influence the significance of specific MC enablers for a company with a different MC implementation maturity level.

Required resources. In my research, I found that the language for describing the resources required for MC implementation is not developed. There is no taxonomy of resources that is used in the MC-IG research substream. The MC-IG substream could probably draw from existing taxonomies and adapt them to make them MC specific.

As-is analysis tools. Research has shown that as-is analysis tools can vary substantially in different MC-IGs. In future research, the MC-IG research substream could benefit from a comprehensive classification of the as-is analysis tools that are used. For example, a distinction could be made between the as-is analysis tools that are applied very quickly, providing an overall view of the company with regard to MC, and tools that are very detailed and can help the company understand exactly which MC enablers to implement. These detailed as-is analysis tools could eventually help to scope and pace implementation of MC enablers.

Hindrance factors. Although hindrance factors have been considered in some articles, there are still a number of open questions; for example, what are the exact hindrance factors? Are some hindrance factors interdependent? Do hindrance factors change from one phase of MC implementation to another? Are hindrance factors context dependent? Are hindrance factors related to the available and required resources? Furthermore, these proposed questions could be followed by indications of how to mitigate the influence of the hindrance factors, how to identify company-specific hindrance factors and whether the hindrance factors are common across the different MC enablers or should have different weights.

1.3.2.2 Building blocks that have high coverage in articles

The results of the analysis show that instruction contents and instruction exemplification have high coverage in the articles (Table 9, Table 11 and Table 13).

Instruction contents ('single enabler' implementation instructions and 'bundled enabler' implementation instructions). Instruction contents can be presented in two ways:

- *'Single enabler' implementation instructions.* The number of enablers for which 'single enabler' implementation instructions are provided per article (usually two or three) is relatively small, bearing in mind that, in total, eight different enablers were recorded in the articles in the study (Table 10 and Table 12). This narrow research scope is likely a consequence of the researchers' previous experiences and opinions regarding the most important enablers for MC implementation. By widening the scope of the enablers addressed through 'single enabler' implementation instructions in future developed MC-IGs should be set as a goal.
- *'Bundled enabler' implementation instructions.* An analysis of the relationships between form postponement and other enablers has shown that there are some contradictory relationships between MC enablers (Table 12); however, other conclusions are possible. For example, part standardization precedes form postponement in one instance, and form postponement precedes part standardization in another instance, and so on. While these findings may seem contradictory, it can be argued that there is no single way to approach some of the precedence relationships. So, starting from the context in which they have been implementing MC, all of the researchers could be right. Taking the context of application (e.g. industry, size of the company, current MC enabler application level, etc.) into consideration, it can be true that form postponement should precede part standardization in one case and that part standardization should precede form postponement in some other case. This analysis supports the viewpoint that there is no one-size-fits-all solution and that context is a very important factor to take into account when implementing MC. Research should also consider applying this reasoning to the linearized

model reported in Figure 3. An interesting research question could be 'When/where are meaningful relationships the reverse of those reported in the linearized model?'

As part of 'bundled enabler' implementation instructions, the *linearity of MC implementation guidelines* (Figure 3) is almost an assumption of the current stream of MC-IG research, and this assumption should be challenged. During the analysis of the 'bundled enabler' implementation instructions, it was apparent that most of the IGs tend to provide linear relationships between the MC enablers. A linear relationship is a pre-set sequence of enablers that does not offer flexibility in deciding the sequence of the implementation steps.

The literature basically provides the linearized model presented in Figure 3 and, in fact, this is the logical sequence of enablers that is derived. But, this does not mean that each *subsequent* step (e.g. product platform development) cannot be done without the previous one (e.g. group technology). Actually, subsequent steps can usually be introduced without the previous steps, with some disadvantages and some advantages as well. A disadvantage of skipping one step could be lower performance in the production system, while an advantage could be reducing the time for implementation. Certainly, the issue of following/not following all the implementation steps in a fixed sequence is something to be investigated.

One of the exceptions to the pattern shown in Figure 3 is presented in the Hernandez, Allen and Mistree (2003, 237) article, which aims to provide the reader with different enabler implementation options (referred to as 'modes') to obtain product variety: 'A mode for managing product variety is any generic approach in a product design or its manufacturing process for achieving systematically a product customization'. More concretely, Hernandez, Allen and Mistree (2003) consider part standardization and product modularization in order to obtain product variety. By using a non-linear approach to achieve product variety, Hernandez, Allen and Mistree (2003) break off from the main bulk of the articles that provide linear enabler relationships and activities for MC implementation.

A non-linear approach is more flexible, with an adjustable implementation sequence, and supports the view that there is no 'one-size-fits-all' solution. A non-linear approach to developing MC implementation guidelines could be one of the directions for the future research.

Instruction exemplification. Instruction exemplification has high coverage in the analyzed articles (Table 13). It can be argued that this is due to the nature of knowledge transfer, where conveying ideas is more effective if an example is provided. It can be concluded that the need for providing examples for implementation instructions has been recognized by researchers and is fulfilled in the articles.

1.3.2.3 Coding dimensions not included in the building blocks

Three coding dimensions that do not address the content of MC-IGs have not been included in the MC-IG building blocks, namely instruction format, research method and knowledge origin. Nevertheless, these dimensions are valuable aspects of MC-IGs and have a significant influence on the acceptability (research method and knowledge origin) and usability (instruction format) of MC-IGs.

Instruction format. During the coding experience, most disagreements were encountered when large parts of plain text were used in the articles. Thus, It can be concluded that the use of multiple formats for implementation instructions is welcome, but effort must be exerted to limit the use of the plain text format where possible. In other words, use of organized text, graphical formats and tabular formats should be preferred over the use of plain text. My experience has shown that plain text usually takes more time to digest, and more disagreements are generated than for the other three instruction formats. This implies that other academics and practitioners could also misinterpret plain text instructions and take a longer time to absorb their content, which in turn reduces the usability of the implementation guidelines. Thus, an interesting question for future research would be: To what extent does the instruction format influence the usability of MC-IGs?

Research method and knowledge origin. The knowledge origin of MC-IGs as well as the research methods used to develop and assess the validity of MC-IGs play an important role in obtaining acceptance and trust from practitioners. Thus, it can be expected that if the knowledge has been sourced from practice and the validity of the IGs has been assessed in practice, the guidelines will be seen as more acceptable and trustable by practitioners.

The MC-IG research substream focuses on the transfer of academic knowledge into practice. The extensive use of knowledge sourced in academia and conceptual modelling for building IGs shows that researchers ground their newly developed IGs within existing academic settings. The extensive use of the case study method to assess the validity of IGs shows an intention of researchers to guarantee that the proposed MC-IGs actually work in practice. The MC-IG analysis has therefore shown that MC-IGs in general strive to integrate academia and practice.

Research on MC-IGs could gain more credibility by using more practice-sourced knowledge. Choosing different research methods could boost the development of MC-IGs that are deeply rooted in practice. Among others, interviews with practitioners (consultants, managers and entrepreneurs) could be used in order to better understand the impact of a specific industry context, company size, degree of MC implementation, and so on, that should be taken into account while developing MC-IGs. Focus groups with MC consultants could be a method to build on the failures and successes accumulated through years of implementation experiences in different contexts. Longitudinal case studies could be used to assess the long-term effect of MC-IG use and could generate specific refinements based on practical experiences of MC implementation, and so on.

The research presented did not take into account how managers learn to implement MC. This learning process could take place through various workshops, professional journals, informal encounters with other practitioners, and so on. Examining how managers learn to implement MC could be one of the research opportunities for future MC-IG development.

1.4 Final remarks

The MC-IG definition provided could be useful to strengthen the bridges between research and practice. Since IGs are a way to transfer research results into practice, recognizing IGs as an important research output will help attract more scholars to this type of research. Having a clear definition of this kind of research will also help to distinguish it from other kinds of research. This distinction, in turn, will help to develop criteria for judging the quality of IG research. In the end, research on IGs will improve and will gain more consideration. This is important given the increasing search to improve the transfer of research results into practice.

The available MC-IGs have been identified. It emerged that MC-IGs are a substream of MC research that is not covered by the mainstream MC literature. Admittedly, the search was limited to the top-rated journals in Scopus. Even though these journals cover a large proportion of the main outlets in which MC research is published, wider coverage would be welcomed. Hopefully, future systematic analyses will be less heavy if IG development and validity assessment are recognized as a specific kind of research product and are therefore openly and clearly stated upfront.

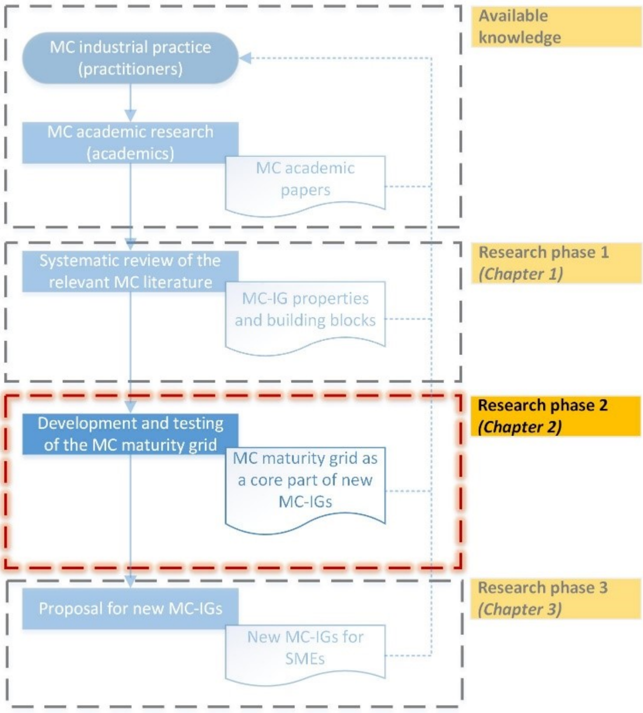
Chapter 1 presented the main results obtained from the research on MC-IGs. Seven MC-IG building blocks were identified, namely MC overview, applicability context of the guidelines, as-is analysis tools, instruction contents, instruction exemplification, required resources and hindrance factors. Analysis of these building blocks led to some specific improvements that MC-IG research could pursue. Further, the importance of instruction formats, research methods and knowledge origin for current and future MC-IG research was discussed. Among more specific results, it emerged that product platform development, IT-based product configuration, product modularization, part standardization and group technology are the MC enablers most frequently considered in the relevant literature. It is suggested that implementation of these five MC enablers should follow a linear sequence. However, this suggestion could be challenged, since there are both pros and cons to linear implementation.

Overall, MC-IG research appears to be a promising substream of MC research, a substream that addresses an issue that is important for both academia and business. However, in order to improve its status, research on MC-IGs needs to be more tightly aligned with the current MC mainstream, and standards for evaluating this research need to be developed.

In conclusion, the main findings of the first research phase, namely the eight MC enablers recorded in the reviewed literature, the identified properties of the MC-IGs, the building blocks of the MC-IGs, and the identified opportunities to improve MC-IGs, are the main inputs for the development of new MC-IGs for SMEs and in particular its core part. This core part is an MC maturity grid for SMEs, the development and empirical testing of which are presented in the following chapter.

CHAPTER 2: Development and testing of the MC maturity grid

Chapter Summary



Chapter 2 presents the second phase of the research. In the second research phase, the core of new MC implementation guidelines that satisfies the properties identified through the systematic literature review is developed. More specifically, the work in the second research phase is focused on SMEs context (context-dependent property), considers all eight MC enablers identified in MC-IG literature (holistic property) and develops a maturity grid appropriate for SMEs as a core part of MC-IGs designed specifically for SMEs (detailed and user-friendly description property). Thus, in order to develop a maturity grid for implementation of MC in SMEs, a methodology by Maier, Moultrie and Clarkson (2012) was followed. The artefact developed is named *MC maturity grid*. The goal of developing the MC maturity grid is to create a context-dependent, holistic, and detailed and user-friendly description artefact that would enable assessment of a company's as-is situation regarding MC and could record changes that occur in the company with implementation of some of the MC initiatives. After the initial MC maturity grid development, the grid was refined and validated through one-to-one interviews with managers, consultants and academics. Further, the MC maturity grid was validated in one manufacturing and one service/software SME through observational evaluation. Finally, the long-term observational evaluation of these two SMEs confirmed that the developed MC maturity grid was capable of recording changes that occurred in the MC maturity level of the companies during a period of almost three years.

2.1 SMEs as an applicability context for MC implementation guidelines

Today, companies all around the world in most industry sectors are facing challenges due to demands for increased product variety. This increase in product variety is also happening for SMEs (Brunoe and Nielsen 2016), putting 'mass customization ... on the agenda in many small and medium sized enterprises' (Svensson and Barfod 2002, 77).

However, management literature hardly addresses SMEs in the context of MC implementation (Lau 2011), leading some authors to conclude that 'out of the literature published on complexity management, and mass customization in general, very little is targeted SMEs' (Brunoe and Nielsen 2016, 42). Further, in management literature it is usually 'large firms, rather than SMEs, that tend to form the greatest parentage of firms pursuing mass customisation' (Brown and Bessant 2003, 708). Brown and Bessant (2003) attribute this to the fact that large companies have more available resources with which they can pursue MC.

Nevertheless, absence of attention in the MC literature does not mean that SMEs do not have a need to pursue MC. On the contrary, the variety of products and the complexity of company systems has been steadily increasing for SMEs in the last decades (Brunoe and Nielsen 2016), which forces them to think of ways to handle the pressures of the changing market. Thus, 'small and medium sized enterprises (SMEs) need to find ways of maintaining their competitive advantages of high customization, short lead time and high quality and overcoming high production cost because of growing competition from large global mass producers', which 'requires SMEs to move to mass customization' (Dean, Tu, and Xue 2009, 1071).

Few articles that focus on SMEs in context of MC provide some important insights. These articles highlight a number of features of SMEs that are of high importance for implementation of MC.

Firstly, SMEs *lack the human and financial resources* for moving towards MC (Brown and Bessant 2003; Ismail et al. 2007; Yeung and Choi 2011). Firstly, lack of human resources is reflected in the fact that while 'putting out every day fires', the SME managers and engineers who should be the drivers of MC implementation rarely have the time to think about innovative ways to enhance their work, products and processes, and to make significant steps towards MC. Secondly, the lack of financial resources means that it is very hard for SMEs to implement broad and holistic MC implementation plans and the 'blue sky' solutions that are often offered through analyses of best-in-class manufacturing and service companies in the literature.

Secondly, lack of resources for MC implementation yields yet another characteristic of SMEs: a *low affinity towards formal approaches for MC implementation*. While researching MC implementation in SMEs, Ismail et al. (2007,

88) ascertain that there is a strong chance that, due to a lack of resources, highly formalized approaches to developing MC products will not be used by the SMEs, but rather 'less formal approaches based on subjective intuition and market knowledge will be used'. Lau (2011, 178), while dealing with product modularization as an MC enabler, states that 'small case firms modularize their products by experience'. It can only be assumed that there could be a middle ground between informal and highly formal approaches to MC implementation.

Thirdly, the tendency of SMEs to *implement improvement initiatives through incremental steps* is another feature derived from lack of resources. In their research conducted on SMEs, Ismail et al. (2007) conclude that the success of the MC implementation in their subject SME came from the ability to understand that they could not do everything in one step. It can be argued that this philosophy of incremental innovation is something to be expected in most SMEs, no matter which industry they belong to.

Fourthly, lack of human resources could also result in *a need for external experts to monitor the MC implementation process*. For example, Ismail et al. (2007, 95) state that 'SME are unlikely to possess the resources and capacity to achieve everything on their own'. Thus, we can expect that the MC-IGs developed for SMEs will not be applied by the company on its own, but will be implemented through the participation of external experts who have a deep understanding of MC and can mentor the SME on its path toward MC.

Fifthly, in some cases, limited resources can imply *the lack of an MC overview*, which could be a specific feature of SMEs. So, in general, SMEs have some knowledge of MC, or of some MC enablers, but this MC knowledge usually comes from their experience with problems that the SME faced in the past and new requirements coming from customers on an everyday basis. Thus, we can expect that in most cases a complete overview and a deep understanding of MC is elusive for SMEs.

Finally, one more important feature of SMEs is the 'volume-variety relationship' (Brunoe and Nielsen, 2016). In general, SMEs produce a lower volume and a higher variety of products, which is closer to craft production than to mass production (Figure 5). Thus, the starting point for an SME will usually be somewhere between craft production and mass customization on a craft production-mass customization continuum (Figure 5). Thus, rather than increasing product variety on the path towards MC (which is usually the case for mass producers), the goal of SMEs is usually to control the product variety (and the resulting complexity it brings to SME systems) and to increase volume per part/component/product.

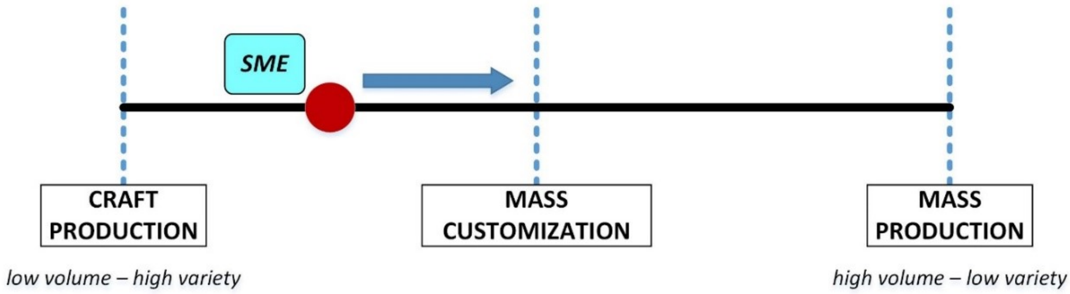


Figure 5. SME position on the craft production-mass production continuum

The present analysis showed that there are enough elements to consider SMEs as a specific context worth exploring from the perspective of MC implementation. Thus, the final choice is made to develop MC implementation guidelines for the SME context. Firstly, this choice is supported by the fact that MC literature has mostly overlooked the SME context for MC implementation. Secondly, SME-specific characteristics need to be addressed through MC-IGs because most of the guidelines present in the literature do not address the specific features of SMEs previously presented.

2.2 Method for MC maturity grid development and evaluation

In order to select a suitable method for developing the core part of the MC-IGs for SMEs, the features of SMEs highlighted by few articles that focus on MC in SMEs (Section 2.1) must be taken into account, namely:

- SMEs are likely to lack resources for implementing advancement initiatives
- SMEs are likely to have low affinity towards highly formalized approaches
- SMEs are likely to have affinity towards incremental steps in implementing changes
- SMEs are likely to have a need for external experts to monitor the MC implementation process
- SMEs are likely to lack a grasp of the MC concept (MC overview)
- SMEs are likely to be positioned between craft production and mass customization on the craft production-mass production continuum (Figure 5)

In order to respond to these issues, a maturity grid was chosen for developing the core part of the MC implementation guidelines:

> Maturity grid is a matrix used by a business or organization as a benchmark to assess how mature its processes are with respect to the maturity grid's defined aim and scope (Crosby 1979; Maier, Moultrie, and Clarkson 2012).

One of the advantages of a maturity grid is that it can be used as an assessment tool as well as an improvement tool (Maier, Moultrie, and Clarkson 2012). Moreover, in the case of voluntary evaluation, 'companies often look for assessments that do not take too long and do not cost too much, which makes maturity grid assessments especially attractive' (Maier, Moultrie, and Clarkson 2012, 138). With a maturity grid, a company can have a holistic approach without using an excessive amount of resources. This is because, in the extreme case, a maturity grid can be used by a single person with the application of his/her own knowledge of the company situation, without information retrieval and without the need for calculations. Furthermore, the literature review on MC-IGs has shown that as-is analysis tools are missing in most MC-IGs (Table 7). Additionally, available as-is analysis tools are focused on specific enablers and do not provide a holistic analysis of the company situation. Regarding the needs of SMEs, maturity grids have been demonstrated as light and holistic tools for company use (Chiesa, Coughlan, and Voss 1996; Hammer 2007; Maier, Moultrie, and Clarkson 2012), which is of great importance for application in SMEs.

The pioneer work on maturity grids was done by Philip Crosby (1979) in the field of quality management. He applied a very simple maturity grid called a quality management maturity grid (Figure 6).

	Stage I: Uncertainty	Stage II: Awakening	Stage III: Enlightenment	Stage IV: Wisdom	Stage V: Certainty
Quality Management	We don't know why we have problems with quality	Is it absolutely necessary to always have problems with quality?	Through management commitment and quality improvement we are identifying and resolving our problems	Defect prevention is a routine part of our operation	We know why we do not have problems with quality

Figure 6. Crosby's quality management maturity grid (adopted from Maier, Moultrie, and Clarkson 2012)

Maturity grids are usually applicable to various industry sectors, do not specify how particular processes should look and do not aspire to provide certification of any kind (Maier, Moultrie, and Clarkson 2012). Companies that use maturity grids usually follow a number of approaches in parallel; thus, maturity grids can be used as stand-alone tools or as part of some larger project (Maier, Moultrie, and Clarkson 2012).

In order to provide a method for development and evaluation of maturity grids, Maier, Moultrie and Clarkson (2012) analyzed more than 20 maturity grids for assessment of organizational capabilities gathered from the literature. In the results of this analysis, a 'roadmap to develop new and evaluate existing maturity grids' was developed (Figure 7). This roadmap is composed of four phases with certain decision points to be covered (Figure 7).

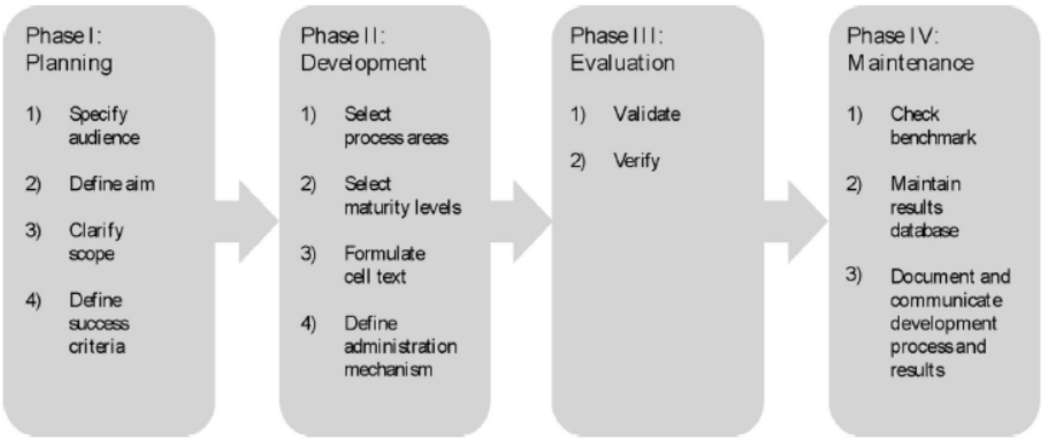


Figure 7. Phases and decision points of the roadmap to develop new and evaluate existing maturity grids (Maier, Moultrie, and Clarkson 2012)

In the rest of this sub-chapter, the phases and decision points of the roadmap to develop new and evaluate existing maturity grids developed by Maier, Moultrie and Clarkson (2012) will be briefly presented. For more detail about the methodology, please refer to Maier, Moultrie and Clarkson (2012).

The roadmap to develop new and evaluate existing maturity grids is composed of four phases—hereafter called *steps* in order to distinguish them from the PhD research phases— namely (excerpts taken from Maier, Moultrie, and Clarkson, 2012):

- Step I – Planning, which 'sees the author of a maturity grid decide on the intended audience (user community and improvement entity), the purpose of the assessment, the scope, and success criteria' (p. 149)
- Step II – Development, which 'defines the architecture of the maturity grid. The architecture has a significant impact on its use. An author makes decisions about the process areas to be assessed, the maturity levels (rating scale) to be assigned, the cell descriptions to be formulated, and the administration mechanism to be used' (p. 150)
- Step III – Evaluation, which 'is an important stage in the development of a maturity grid and serves a number of functions. For example, tests are used to validate the grid, to obtain feedback on whether the grid fulfilled the requirements when applied in practice, and to identify items for refinement. Ideally, evaluations are conducted within companies or institutions that are independent of the development. During this phase, it is important to test input into the grid (choices made during Phases [Steps] I and II) for validity and the results acquired by applying the grid in practice for correctness — in case of benchmarking also for generalizability' (p. 151)
- Step IV – Maintenance, which 'is an ongoing phase. Continued accuracy and relevance of a maturity grid will be ensured by maintaining it over time. Access and provision of necessary resources to maintain the grid will affect its evolution and use. Maintenance becomes necessary as domain knowledge and understanding broadens and deepens. Similarly, current best practice becomes outdated as a result of, for example, new technological developments. Maintenance is especially necessary if detailed and prescriptive activities have been specified in the cell text' (p. 152)

The MC maturity grid has been developed using the above four-step method. The four steps applied in the development of the MC maturity grid were performed at different phases of the PhD research and with different outcomes (Table 18). In the next sub-chapter, the development of the MC maturity grid is presented in detail.

Table 18. Steps and outcomes of the MC maturity grid development

Grid development step	Outcome	Phase of the research in which the step was done
Step 1 - Planning		
Specify audience	- Users: Managers and consultants (practitioners) dealing with implementation of MC in SMEs - Improvement entity: Products and processes in SMEs	Phase 1 – Systematic review of the relevant MC literature Phase 2 – Development and testing of the MC maturity grid
Define aim	To enable holistic assessment of the current company MC maturity level	Phase 1 – Systematic review of the relevant MC literature
Clarify scope	SMEs in need of MC implementation	Phase 2 – Development and testing of the MC maturity grid
Define success criteria (C)	C1: MC maturity grid is understandable to practitioners (usability) C2: MC maturity grid can successfully assess the MC level of SMEs (usefulness)	Phase 2 – Development and testing of the MC maturity grid
Step 2 - Development		
Select process areas	Maturity grid areas were identified starting from the eight MC enablers that emerged from the MC-IG literature review; refinement through interviews with managers, consultants and academics	Phase 2 – Development and testing of the MC maturity grid
Select maturity levels	Maturity levels (3 to 4 for each area) were developed through analytical reasoning based on inputs from MC literature, and were refined through interviews with managers, consultants and academics	Phase 2 – Development and testing of the MC maturity grid
Formulate cell text (intersection of process areas and maturity levels)	Descriptive formulation of cell texts; refinement through interviews with managers, consultants and academics	Phase 2 – Development and testing of the MC maturity grid
Define administration mechanism	Paper-based distribution mechanism through group workshops	Phase 2 – Development and testing of the MC maturity grid
Step 3 – Evaluation		
Validate	Practitioners with high MC knowledge agreed that the proposed grid correctly conveys the meaning of the maturity grid areas and can be used to accurately assess the MC maturity levels of SMEs	Phase 2 – Development and testing of the MC maturity grid
Verify	MC maturity grid meets the defined success criteria (C1 and C2)	Phase 2 – Development and testing of the MC maturity grid
Step 4 – Maintenance		
Check benchmark (and adjust description in cells)	Not a part of the PhD research	Not required. The pace of change in MC best practices in not high. Thus, the period of PhD research is too short to consider implementation of this step
Maintain results database	Gathered obtained results in the planning, development and evaluation phases	Phase 2 – Development and testing of the MC maturity grid
Document and communicate development process results	Publication of the research results in academic journals	To be done in the future by publishing the research results in an academic journal

2.3 Development of the MC maturity grid

The MC maturity grid was developed based on the methodology of Maier, Moultrie and Clarkson (2012), which was already presented in this chapter. Development of the MC maturity grid started from properties of the MC-IGs and the list of MC enablers identified during the literature review research phase. From these two inputs, an initial proposal for the MC maturity grid was derived (Figure 8). Notably, the maturity grid follows the non-linear approach of Hernandez, Allen and Mistree (2003), intentionally challenging one of the main outcomes of the literature review: the linearized model of basic enabler relationships (Figure 3). The initial MC maturity grid proposal (Figure 8) contains eight grid areas, which correspond to the eight MC enablers identified in the literature review phase, and the maturity levels of the initial grid proposal are defined as low, medium and high for all grid areas. The idea of using these three very simple maturity levels was based on the assumption that a certain amount of knowledge of these enablers was present in SMEs, or at least is easily obtainable, and that it would limit the time and efforts needed to perform the assessment.

MC enabler / Maturity level	Product platform development	Product modularization	Part standardization	IT-based product configuration	Group technology	Form postponement	Sourcing configuration for MC	Process modularity
Maturity level 1	Low	Low	Low	Low	Low	Low	Low	Low
Maturity level 2	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Maturity level 3	High	High	High	High	High	High	High	High

Figure 8. Initial proposal for the MC maturity grid based on the outputs of the literature review research phase

In order to assess and refine the developed MC maturity grid (Figure 8), interviews were conducted with managers, consultants and academics who are experts in MC and have vast experience with SMEs. The aspects to be refined were not preset, so the procedure was highly iterative and open. Interviews were conducted by alternating manager, consultant and academic input in order to produce balanced output without the dominance of any of the three expert groups.

The results from the interviews with experts are as follows:

- It was concluded that 'low', 'medium' and 'high' cannot be used for maturity level descriptions in the grid areas. Understanding these three notions in order to advance each enabler would be subject to bias generated by the different experience of the practitioners and their understanding of each grid area. In addition, they would have been too limited to stimulate the generation of ideas for potential improvements. As a result, it was decided to introduce text into the cells in order to describe each maturity level of each grid area. This descriptive text was supposed to eliminate misunderstandings and move the grid closer to the needs of SMEs.
- Two MC enablers were excluded from the list of enablers that should be part of the MC-IGs for SMEs. These enablers are *sourcing configuration for MC* and *process modularity*. Sourcing configuration for MC was excluded because it was marked as too advanced and abstract for most SMEs to grasp. Process modularity was excluded as it was recognized as being very similar or for the most part overlapping with cell manufacturing as part of the general concept of group technology.
- Three MC enablers were added to the list of MC enablers that should be included in the MC maturity grid, namely *mixed-model assembly lines*[4], *single minute exchange of die* (SMED)[5], and *virtual build to order* (VBTO)[6]. These are MC enablers more related to production and production planning. Actually

[4] A *mixed-model assembly line* is an assembly line capable of producing 'units of different models in an arbitrary inter-mixed sequence' (Becker and Scholl 2006, 696, based on Bukchin, Dar-El, and Rubinovitz 2002).

[5] *Single minute exchange of die* (SMED) 'refers to a theory and techniques for performing setup operations in under ten minutes, i.e., in a number of minutes expressed in a single digit. Although not every setup can literally be completed in single-digit minutes, this is the goal of ... [SMED], and it can be met in a surprisingly high percentage of cases. Even where it cannot, dramatic reductions in setup time are usually possible' (Shingo 1985, xix).

[6] *Virtual build to order* (VBTO) 'is a form of order fulfilment system in which the producer has the ability to search across the entire pipeline of finished stock, products in production and those in the production plan, in order to find the best product for a customer' (Brabazon and MacCarthy 2004, 155). This approach reduces the trade-off between customization, delivery lead-time and working capital.

production and production technology were somewhat underrepresented areas in the starting list of enablers. In the end, understanding of the MC concept led to a need for experts to strengthen the presence of this type of MC enabler. A number of other suggestions provided by single experts have not been included in order to limit the complexity of the grid. Thus, after the interviews with experts, the final list of MC enablers to be used as input for development of MC maturity grid was generated:

1. Product platform development
2. Product modularization
3. Part standardization
4. IT-based product configuration
5. Group technology
6. Form postponement
7. Single minute exchange of die (SMED)
8. Virtual build to order (VBTO)
9. Mixed-model assembly lines

- It was concluded that enablers cannot be used as grid areas. The main concern was overlap of the enablers in the minds of a number of people, which would in effect make the MC maturity grid unusable. Although some of the overlaps could already be perceived during the analysis of the MC enabler relationships in the literature review (e.g. contradictory relationships between form postponement and other MC enablers [Table 12]), additional overlaps were recorded in the interviews. This led to the decision that grid areas do not necessarily have to present enablers. Instead, grid areas can also represent a part of an enabler or a mix of enablers, or their intersections, etc. With this new approach to defining grid areas, it was possible to develop an MC maturity grid with columns that do not overlap in the minds of users.

The MC maturity grid was further refined and developed starting from the list of nine MC enablers. Nine MC enablers were mapped to the grid areas, and a strategy of inserting descriptive text for maturity levels in every grid area was adopted.

Since insertion of descriptive text in the cells of the grid meant increasing the size of the grid, the size of the grid was set to A3 format in order for it to be usable and readable. Although this format is larger than A4, which could present a problem, the readability of A4 is not satisfactory for the intended MC maturity grid use, which is paper-based distribution through group workshops.

After a second version of the maturity grid was developed in an iterative process (Figure 11), further interviews led to the following suggestions:

- The text in the MC maturity grid is too long and could be hard to understand and use by SMEs. At the same time, there were suggestions that long text will not hinder the usability of the grid and that removal of the text would cause lesser understandability by the SME managers and engineers. As a compromise, it was decided to cut some text in grid areas 3 and 7, using '+' as a sign that the next maturity level only adds some text to the previous one. Thus, the proposal for making the text shorter was taken into account, but confirmation was sought in the practical implementation and reactions of the SME staff to the text.
- There was a suggestion that some of the words that are most important for conveying the meaning of a certain maturity level should be emphasized. This approach was applied in grid area 8 in order to test this solution in practice.

Next, the procedure for identifying grid areas based on the principles derived from the interviews with experts is presented.

2.3.1 Identified grid areas of the MC maturity grid

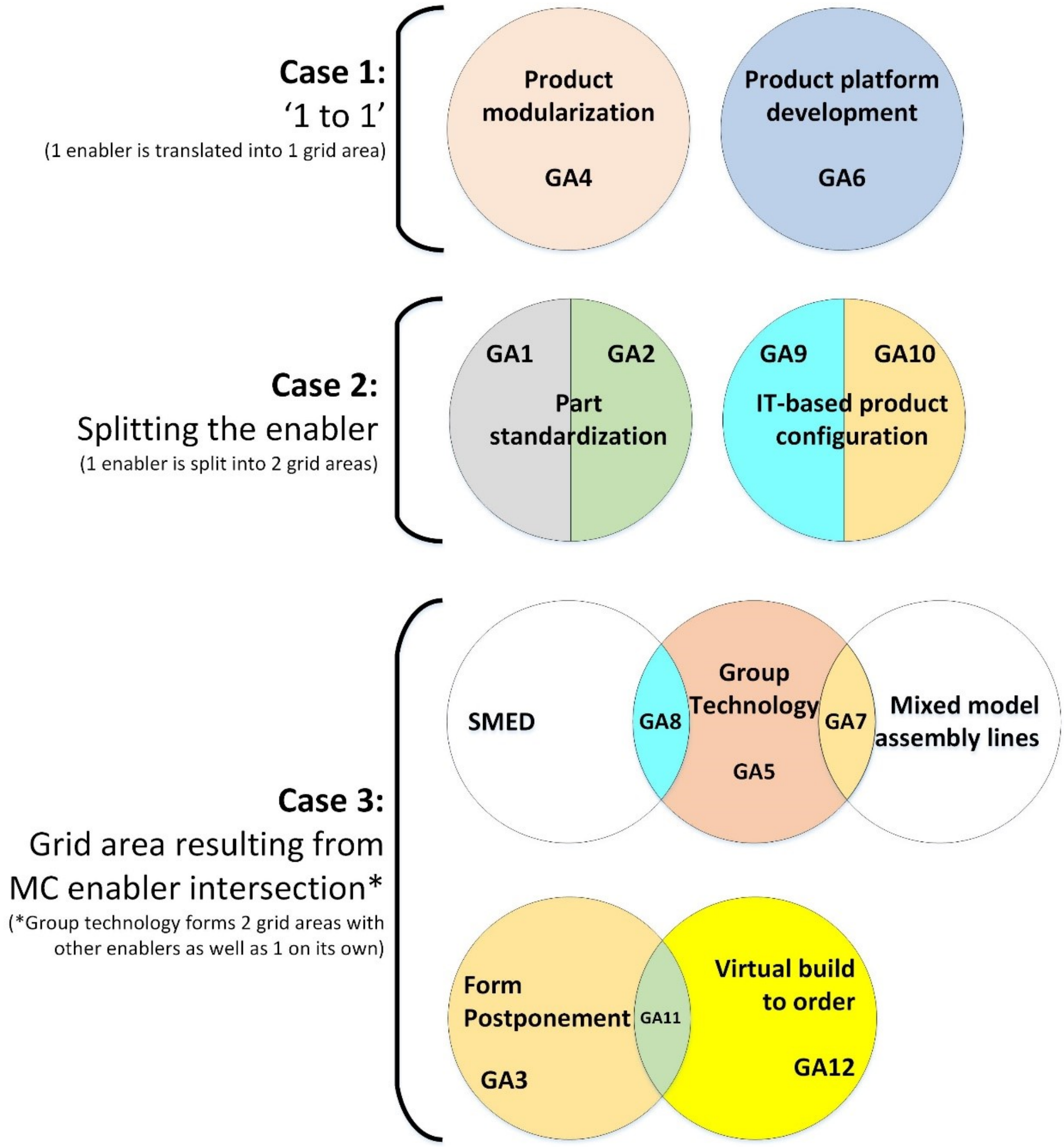
Identification of grid areas was done in iterative way, mainly because:

- In the initial interviews with the experts, overlaps between MC enablers were recorded
- The enablers were not regarded as equal. Some of the MC enablers were regarded as more basic, while others were regarded as more advanced, eventually too advanced for the types of companies for which the grid is intended

Analysis of grid areas (GAs[7]) and maturity levels was done during the interviews. Subsequently, the analysis was followed by a synthesis leading to a highly iterative process of MC maturity grid refinement.

In the outcome, twelve grid areas were identified (GAs in Figure 9). Some of the grid areas represent only one MC enabler, while others present a combination of MC enablers. There are still other grid areas that represent only parts of one MC enabler, as in the case of the two grid areas that represent different aspects of part standardization.

[7] Abbreviation 'GA' for 'grid area' is used only in this section 2.3 to facilitate the presentation of the MC maturity grid development



Legend:
GA – *Grid area*
SMED – *Single minute exchange of die*
GA1 – *Grid area 1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed*
GA2 – *Grid area 2 Standardization of parts: Day-by-day limitation of new parts introduction*
GA3 – *Grid area 3 Standardization of production sequences*
GA4 – *Grid area 4 Product modularization*
GA5 – *Grid area 5 Grouping of parts into families through a similarity-based classification system*
GA6 – *Grid area 6 Product space organized in clearly distinguished product families*
GA7 – *Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families*
GA8 – *Grid area 8 Low and continuously reduced set-up times*
GA9 – *Grid area 9 Technical configurator*
GA10 – *Grid area 10 Sales configurator*
GA11 – *Grid area 11 Keeping stocks at optimal levels*
GA12 – *Grid area 12 Sophisticated and dependable supports for determining available to promise*

Figure 9. Identification of grid areas

The twelve grid areas that were identified (Figure 9) are presented and defined below.

- *Grid area 1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed* – This grid area is the first (of two) that represents part standardization (the second one is GA2 - Figure 9). The main principle is to determine whether the company does the rationalization of product space through periodic standardization of parts
- *Grid area 2 Standardization of parts: Day-by-day limitation of new parts introduction* – This grid area is the second (of two) representing part standardization in the maturity grid (the second one is GA1 - Figure 9). The basic idea is that through the work of design/production engineers and purchasing staff, attention is given to standardizing new parts introduced into production. Even more, the goal is to limit the introduction of new parts in order to prevent an increase in system complexity
- *Grid area 3 Standardization of production sequences* – This is the first grid area (of two) that represents the form postponement enabler (the second one is GA11 - Figure 9). The main idea is that with the work of design engineers, production engineers and the entire organization, attention is focused on introducing new production sequences into production. The goal is to limit the proliferation of new production sequences and, as a result, to limit the increase in system complexity.
- *Grid area 4 Product modularization* – This grid area presents product modularization. The main idea is to determine whether the company develops its products (product families) on the principle of modularity, as well as to determine if product platforms based on modules exist in the product portfolio.
- *Grid area 5 Grouping of parts into families through a similarity-based classification system* – This is the first grid area (of three) that represents the group technology enabler (the second is GA7 and the third is GA8 - Figure 9). This grid area presents one of the bases of the group technology enabler: the use of a classification system. The main principle is that a classification system should be created on the basis of part similarity in terms of shape, size and material. This sort of classification system leads to formation of part groups that will be produced in similar production processes.
- *Grid area 6 Product space organized in clearly distinguished product families* – This grid area represents the product platform development enabler and product families as a direct result of product platform

application. The basic idea is to recognize the existence of product families, either modular or scaled ones (i.e. scale-based)[8].

- *Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families* – This grid area represents mixed-model assembly lines, and at the same time is the second grid area (of three) that represents group technology (the first is GA5 and the third is GA8 - Figure 9). The main idea is to design a shop floor to achieve the highest speed and efficiency in processing the part/product families.
- *Grid area 8 Low and continuously reduced set-up times* – This grid area represents SMED, and is the third grid area (of three) that represents group technology - use of group tools (the fist one is GA5 and the second one is GA7 - Figure 9). The main idea is the application of a system for continuous lowering of set-up times.
- *Grid area 9 Technical configurator* – This grid area is the first (of two) representing IT-based product configuration (the second one is GA10 - Figure 9). The main idea of this grid area is the development of a technical configurator that is capable of automatically generating bills of materials (BOMs) for all possible product variants.
- *Grid area 10 Sales configurator* – This grid area is the second (of two) representing IT-based product configuration (the first one is GA9 - Figure 9). The main idea of this grid area is the development of a sales configurator that would enable customers, salesmen and the technical staff responsible for sales to choose all product characteristics and control the compatibility of these characteristics.
- *Grid area 11 Keeping stocks at optimal levels* – This is the second (of two) grid areas representing form postponement (the first one is GA3 - Figure 9). It is also the first grid area (of two) representing virtual build to order (the second one is GA12 - Figure 9). The main idea of this grid area is the development of a system for production planning and control that is capable of providing an optimal level of service to the next phase in the production process, assembly and product delivery to the customer while maintaining the level of working capital (finished products, modules, components, parts and raw materials) at the optimum level. Thus, this grid area deals with the

[8] A scale-based product family is a 'product family in which features change from product to product through different values of the scaling variables' (Simpson, Maier and Mistree 2001, 3)

trade-off between maximum service and the minimum amount of working capital under conditions of high product variety (i.e. mass customization).

- *Grid area 12 Sophisticated and dependable supports for determining available to promise* – This is the second grid area (of two) representing virtual build to order (the first one is GA11 - Figure 9). The main idea of this grid area is the development of a sophisticated and reliable support system for determining available to promise. Thus, the goal is to enable the production system to determine when a product (or a product variant) that was promised to the customer will be available for delivery under the conditions of high product variety (i.e. mass customization). In addition, the goal is to introduce a system that will enable changes in the product configurations that are already in production without increasing the product price and without influencing the level of service provided to the customer.

In Figure 10, the details of how the MC enablers were mapped to the grid areas are shown. In the presented matrix, nine MC enablers have been mapped into twelve grid areas.

GRID AREAS / MC ENABLERS	GA1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	GA2 Standardization of parts: Day-by-day limitation of new parts introduction	GA3 Standardization of production sequences	GA4 Product modularization	GA5 Grouping of parts into families through a similarity-based classification system	GA6 Product space organized in clearly distinguished product families	GA7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	GA8 Low and continuously reduced set-up times	GA9 Technical configurator	GA10 Sales configurator	GA11 Keeping stocks at optimal levels	GA12 Sophisticated and dependable supports for determining available to promise
Part standardization	X	X	O	O					O		O	O
Product modularization	O			X		O			O	O	O	O
Product platform development			O	O		X	O	O	O	O	O	O
Group technology	O	O	O		X		X	X			O	O
Mixed-model assembly lines			O				X	O			O	O
SMED							O	X			O	O
Form postponement			X	O		O	O	O			X	O
IT-based product configuration	O	O	O	O		O		O	X	X	O	O
Virtual build to order									O	O	X	X

Legend:

GA - *Grid area*

X - *The enabler is mapped to the grid area; the MC enabler in the row constitutes the grid area specified in the column*

O - *An impact exists; the MC enabler in the row facilitates/forces to do at least part (or some aspect of) the grid area specified in the column*

Figure 10 Map of the relations between MC enablers and grid areas

Overall, there are four possibilities for enabler mapping that were already mentioned while defining the grid areas:

1) One-to-one mapping – when one MC enabler is mapped to one grid area (represented with a single 'X' sign in one enabler row; for example, the Product modularization row in Figure 10). More specifically, the MC enabler in the row constitutes one and only one grid area specified in the column. These cases represent clear mapping, which is not further elaborated.
2) Splitting the enabler – when one MC enabler is split into more than one grid area (represented with two or more 'X' signs in a single enabler row – for example, the Group technology row in Figure 10). More specifically, the MC enabler in the row constitutes more than one grid area specified in the columns. These cases are drawn from the MC literature and will be elaborated in the following subsections of this chapter.
3) An impact exists – when an enabler has an impact on a specific grid area (represented with an 'O' sign in the cell in Figure 10). More specifically, the MC enabler in the row facilitates/forces to do at least part (or some aspect of) the grid area specified in the column. Impacts on the specific grid areas have been gathered through interviews with experts. These impacts, though not directly supported by the literature, are elaborated and supported by examples and logical reasoning in the following subsections of this chapter.
4) No impact exists – when an enabler has no impact on a specific grid area (represented with an empty cell in Figure 10). These cases are not further elaborated.

In the following subsections of this chapter, the mapping of the nine MC enablers to grid areas is further elaborated.

Part standardization in the MC maturity grid

While presenting his strategy for part standardization, Anderson (2014, 183) differentiates the part standardization done on existing products and the part standardization done on new products. Anderson (2014, 184) proposes to list existing parts and circulate the list to design engineers in order 'to at least stop designers from adding new parts when they could use an existing one', that is, to stop part proliferation in new products. As regarding the existing products, Anderson (2014, 184-187) proposes steps to 'Clean Up Database Nomenclature', 'Eliminate Approved but Unused Parts', 'Eliminate Parts Not Used Recently', 'Eliminate Duplicate Parts' and 'Prioritize Opportunities', that is, to rationalize product part list in existing products. Accordingly, in the developed MC maturity grid, part standardization is split into two grid areas:

- Grid area 1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed
- Grid area 2 Standardization of parts: Day-by-day limitation of new parts introduction

These two grid areas are devoted solely to part standardization. In addition to these two grid areas that directly represent part standardization, part standardization plays an important role in the following five grid areas:

- Grid area 3 Standardization of production sequences – with standardization of parts, the proliferation of production sequences is automatically limited
- Grid area 4 Product modularization – in standardizing parts, we may apply criteria that increase modularization, for example while standardizing the tops of a pen, we can delete the tops that include the name of the producer so that the top has only the function of covering the pen and not also the function of communicating the producer
- Grid area 9 Technical configurator – the reduction of the number of parts reduces the effort required to develop the technical model within the technical configurator
- Grid area 11 Keeping stocks at optimal levels – the reduction of the number of parts makes it easier/possible to use simpler and more effective production planning and control systems (PPCSs) such as those implemented following LEAN production approaches
- Grid area 12 Sophisticated and dependable supports for determining available to promise – reducing the number of parts makes it easier to determine available to promise and reliable delivery dates because it makes the entire system simpler

Product modularization in the MC maturity grid

In the developed MC maturity grid, product modularization is presented through one grid area:

- Grid area 4 Product modularization. This grid area is dedicated only to product modularization.

In addition, the product modularization enabler plays an important role in the following six grid areas of the maturity grid:

- Grid area 1 Standardization of parts: periodical rationalization to eliminate parts no longer needed – product modularization implies standardization of interfaces between module families, and these standardized interfaces reduce the number of different parts. Product modularization also forces grouping of parts based on their functions and therefore supports standardization evaluations

- Grid area 6 Product space organized in clearly distinguished product families – when product modularization is done, a set of products builds a product family, that is, these products share modules and processes and are similar in terms of functions delivered
- Grid area 9 Technical configurator - the modularization of a product family reduces the effort required to develop the technical model for that product family within the technical configurator because it reduces the constraints that must be inserted
- Grid area 10 Sales configurator – the modularization of a product family reduces the effort required to develop the commercial model for that product family within the sales configurator because it reduces the constraints that must be inserted
- Grid area 11 Keeping stocks at optimal levels – the modularization of a product family facilitates the setting up of an assemble-to-order (ATO) system in which modules are produced based on forecasts and final products are assembled based on orders
- Grid area 12 Sophisticated and dependable supports for determining available to promise – product modularization reduces differences in product architecture and increases the use of the same processes. All of these increase the predictability of the system, and in particular, the available to promise and the predictability of promise dates for delivery

Product platform development in the MC maturity grid

In the developed MC maturity grid, product platform development is presented in one grid area:

- Grid area 6 Product space organized in clearly distinguished product families. This grid area is dedicated only to product platform development.

The literature on product platforms broadened the concept of product platforms. However, in SMEs one of the main issues is a clear definition of product families. The definition of product families is, in turn, a requirement without which all other aspects of product platforms cannot be implemented. For these reasons, the focus is on the organization of clearly distinguished product families.

In addition, the product platform development enabler plays an important role in the following eight grid areas of the maturity grid:

- Grid area 3 Standardization of production sequences – Since a product family requires similarity in the processes for products belonging to the family, the definition of product families promotes some standardization of processes across the products belonging to the same product family. Product platform has been invented to stimulate the reuse of processes across product models that are developed with the passing of the time

- Grid area 4 Product modularization – The grouping of products based on the similarity of functions and processes facilitates the modularization of products
- Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families – In order to be able to organize the assembly process based on product families, product families need to have already been defined
- Grid area 8 Low and continuously reduced set-up times – Usually, the set-up time to move from one product to another of the same product family is much lower than moving from one product to another that belongs to a different product family. Therefore, organizing products in product families may help reduce set-up times
- Grid area 9 Technical configurator – Usually different technical models are developed for different product families. Sometimes product configurators have functions to copy product models from one family to another one. Therefore, in order to implement technical product configurators, we need to organize products into product families
- Grid area 10 Sales configurator – Properly designed and clearly distinguished product families make the creation and implementation of a sales configurator much easier
- Grid area 11 Keeping stock at optimal levels – When there is a high number of product variants and there are some similarities within some subsets of the product variants, it is convenient to plan subsets of product variants. Therefore, organizing products in families may facilitate production planning
- Grid area 12 Sophisticated and dependable supports for determining available to promise – Since the products of a given product family have a lot of process similarity, in a high number of cases, they will have the same/very similar throughput time. Therefore, the company often has the same available to promise date for most of the products of the same family

Group technology in the MC maturity grid

While describing advantages of group technology, Burbidge (1992, 1212) states that 'There are major advantages to be obtained by seeing that all *similar operations* on *these similar parts* are routed to the *same machines*, because this brings together parts which can be made *with the same tools at the same setup*, reducing the setup time per part (sequencing) and increasing capacity' (italics added). Thus, group technology includes notions of part similarity, operation/machine similarity, and use of the same tools to reduce setup times. In effect, these three notions are operationalized through a part classification system, cell manufacturing and group tools. Accordingly, in the developed MC maturity grid, group technology is split into three grid areas:

- Grid area 5 Grouping of parts into families through a similarity-based classification system
- Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency in processing part/product families
- Grid area 8 Low and continuously reduced setup times

Notably, grid area 7 and grid area 8 do not solely cover the group technology enabler. Besides the group technology enabler, grid area 7 is also part of the mixed-model assembly lines enabler, while grid area 8 is also part of the SMED enabler.

In addition, the group technology enabler plays an important role in the following five grid areas of the maturity grid:

- Grid area 1 Standardization of parts: Periodical rationalization to eliminate parts no longer needed – Use of a classification system highlights the parts that should be eliminated. The classification system facilitates this procedure in the sense that parts that do not fit the production system are more likely to be eliminated or subjected to standardization, that is, redesigned
- Grid area 2 Standardization of parts: Day-by-day limitation of new parts introduction – Use of classification system facilitates and stimulates the use of existing parts by grouping the parts into part families. Having parts grouped in part families it is more likely that if a similar part is already being produced, a new part will not be introduced, but its role will be replaced by a similar part belonging to the same part family
- Grid area 3 Standardization of production sequences – Group technology tends to assign an already available product sequence to new parts, thereby limiting the proliferation of production sequences
- Grid area 11 Keeping stocks at optimal levels – By grouping machines to process parts belonging to the same part family (with high process similarity), the production system is divided into autonomous subunits, which, in turn, substantially simplifies PPCS activity
- Grid area 12 Sophisticated and dependable supports for determining available to promise – By grouping machines to process the parts belonging to the same part family (with high process similarity), the production system is divided into autonomous subunits, which, in turn, makes determining the available to promise date much easier

Mixed-model assembly lines in the MC maturity grid

In the developed MC maturity grid, mixed-model assembly lines are presented in only one grid area:

- Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families

In addition, the mixed-model assembly lines enabler plays an important role in the following four grid areas of the maturity grid:

- Grid area 3 Standardization of production sequences – Mixed model assembly lines tend to limit the introduction of new production sequences through standardization of assembly processes
- Grid area 8 Low and continuously reduced setup times – Tools designed for part/product families are used on mixed-model assembly lines, thus lowering the setup times. Also, the line itself has been designed/redesigned for a certain product family
- Grid area 11 Keeping stocks at optimal levels – The ability of mixed-model assembly lines to assemble different products in turn simplifies the planning process, since the company in not forced to group production in batches
- Grid area 12 Sophisticated and dependable supports for determining available to promise – Use of mixed model assembly lines for product families enhances the ability of the company to determine available to promise by lowering the setup times so the sequence of products does not influence efficiency

Single minute exchange of die (SMED) in the MC maturity grid

In the developed MC maturity grid, SMED is presented in one grid area:

- Grid area 8 Low and continuously reduced set-up times

In addition, the SMED enabler has an important role in the following three grid areas of the maturity grid:

- Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families – Use of SMED significantly reduces throughput time by lowering set-up times for machines
- Grid area 11 Keeping stocks at optimal levels – Reduction of set-ups reduces the need to produce large batches and increases capacity. Both of these increase the effectiveness of PPCS in balancing service and stocks
- Grid area 12 Sophisticated and dependable supports for determining available to promise – faster change of tools leads to possibility of batching and sequencing products in whatever way without negatively effecting efficiency. This freedom in turn eases determining available to promise

Form postponement in the MC maturity grid

While conceptualizing model for form postponement, Skipworth and Harrison (2006) state that 'The manufacturing planning and control systems challenge is to optimize the two contrasting stages of manufacture (pre- and post-CODP[9])'. Pre-CODP manufacturing stage 'involves the forecast-driven production of a relatively narrow range of generic products' (Skipworth and Harrison 2006, 1631), implying that the standardization of production sequences should be applied. Post-COPD 'manufacturing stage should focus on 'agile supply' — where maximizing customer service in terms of short, reliable order lead-times is the key factor' (Skipworth and Harrison 2006, 1631, based on Mason-Jones and Towill 1999) which implies that stock levels should be kept optimum (i.e. cost of stocks should be minimized while service levels maximized). Accordingly, in the developed MC maturity grid, form postponement is split into two grid areas:

- Grid area 3 Standardization of production sequences
- Grid area 11 Keeping stocks at optimal levels

Notably, the first of these two grid areas (grid area 3) is dedicated solely to the form postponement enabler, while the second grid area (grid area 11) is also part of virtual build to order enabler. In addition, the form postponement enabler has an important role in the following five grid areas of the maturity grid:

- Grid area 4 Product modularization – Postponing final product differentiation stimulates product modularization as a way to successfully delay differentiation of the products
- Grid area 6 Product space organized in clearly distinguished product families – In order to postpone product differentiation, products are grouped into families. When a group of products is subjected to a form postponement initiative, their inclusion in a product family becomes more evident, since the commonality in processes and the differentiations in attributes become clearer
- Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families – Working toward implementing form postponement, that is, moving the differentiating operation downstream, facilitates the use of cell manufacturing and mixed-model assembly lines as an effective means of delaying differentiation of product form
- Grid area 8 Low and continuously reduced set-up times – Big sections of production sequences are the same across products and therefore setups are not

[9] Customer order decoupling point (CODP) 'is the point in a value-adding process where a product is linked to a specific customer order' (Skipworth and Harrison 2006, 1629)

needed. By reducing the number of setups, the company reduces the total time dedicated to setup
- Grid area 12 Sophisticated and dependable supports for determining available to promise – Increasing the number of product sequences that are in common across products facilitates determining the available to promise dates

IT-based product configuration in the MC maturity grid

Forza and Salvador (2007, 57) divide the product configuration process (and system) into two distinct but interconnected parts, namely, the commercial configuration process (and system) and the technical configuration process (and system). Following this logic, in the developed MC maturity grid, IT-based product configuration is split into two grid areas:

- Grid area 9 Technical configurator
- Grid area 10 Sales configurator

These two grid areas are dedicated only to the IT-based product configuration. In addition, the IT-based product configuration enabler has an important role in the following eight grid areas of the maturity grid:

- Grid area 1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed – Using the product configurator pushes the company to plan periodic rationalization of parts, with the need to determine optimal variety of parts for the designed solution space
- Grid area 2 Standardization of parts: Day-by-day limitation of new parts introduction – Using the product configurator forces the company to more strictly control the introduction of new parts in order to maintain an optimal level of part variety
- Grid area 3 Standardization of production sequences – Development of the product configurator promotes definition of the product space. Once the product space is defined, it becomes natural to somehow limit the differences in production sequences. If the product configurator also manages production sequences, there can be a deliberate effort to standardize them
- Grid area 4 Product modularization – On the one hand, implementation of a product configurator usually considerably improves the formalization and rationalization of the product space, which in turn facilitates the increase of the family modularization level. On the other hand, companies that wish to introduce a product configurator are pushed to increase product modularization, since a higher product modularity level facilitates the implementation of a product configurator. This facilitation is due to the fact that modularization enables the configuration of products by assigning

different product functions to different modules, which are then easier to implement into product configurators as customer choices

- Grid area 6 Product space organized in clearly distinguished product families – The design and implementation of a product configurator requires organizing products into product families, which requires companies to better understand the similarities and differences among their products
- Grid area 8 Low and continuously reduced set-up times – Grouping products into product families (based on similarity in design and function) in order to implement a product configurator eliminates a great deal of set-up time. In this way, implementing a product configurator indirectly eliminates a portion of set-up time in the system. In addition, a product configurator reduces the presence of special parts and concentrates the demand on repetitive/more common parts
- Grid area 11 Keeping stocks at optimal levels – Controlling the product variety caused by introducing a product configurator (through introduction of product families and increasing part demand concentration) leads to easier production planning and control. In addition, the accuracy of the BOM increases
- Grid area 12 Sophisticated and dependable supports for determining available to promise – The implementation of a product configurator increases the formalization and rationalization of product space as well as the concentration of part demands. In addition, it reduces errors in the product documents used by the material planning and control system (MPCS). The consequence is that it becomes easier to find reliable mechanisms to determine the available to promise

Virtual build to order in the MC maturity grid

The main purpose of virtual build to order (VBTO) is to enable the producer to determine available to promise through searching the 'entire pipeline of finished stock, products in production and those in the production plan, in order to find the best product for a customer' (Brabazon and MacCarthy 2004, 155). But, due to a poor stock mix compared to conventional production systems, VBTO can result in increased 'stock levels and average customer waiting time' (Brabazon and MacCarthy 2006, 523). In order to mitigate the negative effects on stocks and waiting times, Brabazon and MacCarthy (2006, 523) propose 'introducing feedback between the sequence fed into the pipeline and the current stock mix, and to the use of rules for allocating pipeline products to customers'. Accordingly, the goal of VBTO becomes not solely determining available to promise, but also optimal management of stocks. Thus, in the developed MC maturity grid, VBTO is split into two grid areas:

- Grid area 11 Keeping stocks at optimal levels

- Grid area 12 Sophisticated and dependable supports for determining available to promise

The first grid area (grid area 11) is also constituted from the form postponement enabler, while the second grid area (grid area 12) is dedicated solely to virtual build to order. In addition, the virtual build to order enabler plays an important role in the following two grid areas of the maturity grid:

- Grid area 9 Technical configurator and grid area 10 Sales configurator – If VBTO is implemented, there is a good formalization of a product space and the way the product features are introduced into the production processes. There is also the capability to easily compare different product variants to understand whether one can be transformed to the other. All of this knowledge formalization and all of the rationalization behind this application of VBTO facilitate the implementation of the technical and sales configurators

2.3.2 Identified maturity levels of the MC maturity grid

In the previous part of the chapter, the process of identifying the twelve grid areas was presented. The overlaps between enablers and the mapping of these enablers to grid areas have been analyzed and elaborated below.

In parallel with the identification of grid areas, through the use of literature, analytical reasoning and an iterative interview process with managers, consultants and academics, maturity levels have been developed for each of the grid areas (Figure 11). There are three or four maturity levels for each grid area. Level 1 represents the lowest maturity level of the SME in the specific grid area, while level 4 presents the highest maturity level of the SME in the specific grid area. Notably, for two grid areas (1 and 8), maturity level 3 is the highest. Next, maturity levels will be presented and defined in more detail for each grid area.

Grid area =>	1	2	3	4	5	6	7	8	9	10	11	12
Maturity level ‖ V	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Product modularization	Grouping of parts into families through a similarity-based classification system	Product space organized in clearly distinguished product families	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	Low and continuously reduced set-up times	Technical configurator	Sales configurator	Keeping stocks at optimal levels	Sophisticated and dependable supports for determining available to promise
1	Never done	No attention is paid to parts proliferation by the organization, design/production engineers and purchasing staff	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	No modularization at all	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	No product families (modular and/or scaled) exist	Machines are clustered on the shop floor based on their functional similarity	Set-up times are VERY LONG; no systematic reductions of set-up times are being applied	Bills of materials (BOMs) and production sequences (if present) are manually defined by production engineers, eventually copied and modified from similar BOMs/production sequences	Customers, salesmen and technical-sales employees do not have any structured support in choosing all the specific characteristics of the product and in controlling their compatibility	We do not have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) and maintain working capital (finished products, modules, components, parts and raw materials) at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stock or that are in production are available to promise
2	There is a systematic procedure to eliminate parts no longer needed and this procedure is done periodically for some part families	No guidelines and no SW support exist, but design/production engineers and purchasing staff pay attention to parts proliferation	It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	In some of our product families, the products have been thought about in such a way that each product function is performed by a specific chunk and does not need to interact with other chunks	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through use of production and design engineers' experience; no structured classification system exists	A portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. But, the clustering is not guided by design procedures	Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated	Set-up times are NEITHER LONG NOR SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) <u>or</u> by application of special tools dedicated to part families and/or product families	For some product families, BOMs and/or production sequences are automatically generated for a lot of possible variants of the product family, starting from the provided product specifications	Customers, salesmen and the technical-sales employees have structured support (but do not have any SW support) in choosing all the specific characteristics of the product and in controlling their compatibility	We have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an acceptable level	If we look for a certain quantity of a given finished product, we know how much of it is available to promise in our stocks and how much is available to promise in production, but in the latter case, we are not really dependable regarding when they will be available in the warehouse. If the product is not yet launched into production, we apply some fixed lead times for the promise that are common for several products
3	There is a systematic procedure to eliminate parts no longer needed, and this procedure is done periodically for all part families	Guidelines for design/production engineers and purchasing staff exist and are applied; no SW support	+ there are rules and SW support to limit the introduction of new production sequences	We thought all of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through a structured manual classification system	A considerable portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures. The distinction between product families is good, but can still be considerably improved	+ the positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through autonomous production units	Set-up times are VERY SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up etc.) <u>and</u> by application of special tools dedicated to part families and/or product families	For almost all product families, BOMs and/or production sequences are automatically generated for most of the possible variants of the product family, starting from the provided product specifications	Customers and/or salesmen and/or technical sales employees use SW that supports them in choosing the main characteristics of the products and in controlling their compatibility (at least for the most important product families)	We have a production planning and control system that can assure a very good service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at a very low level	We know exactly how much of each product is available to promise, both in our stocks and in production and, in the latter case, we are very dependable regarding when the product will be available in the warehouse
4		Guidelines for design/production engineers and purchasing staff exist and are applied very rigorously; SW support exists	+ we make production sequences that differentiate products as late as possible	Our modules may have a longer life than single product families (product platforms exist)	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through an automatic (SW) classification system	The whole product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures that are deeply absorbed by the whole company's organization. Product families are clearly distinguished and do not overlap	+ a system is in place to continuously improve the speed and the efficiency of the autonomous units in processing the parts/product families		BOMs and production sequences (if needed) are automatically generated for almost all possible variants, starting from the provided product specifications	Customers and/or salesmen use SW that supports them in choosing all the characteristics of the products and in controlling their compatibility (for all or almost all of the product families)	We have a production planning and control system that can assure us an optimal service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an optimal level	We are able to tell exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Figure 11. Second variant of the MC maturity grid developed through use of literature, analytical reasoning and iterative interviews with managers, consultants and academics

Grid area 1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed

This grid area is the first (of two) that represents part standardization (the second one is GA2 - Figure 9). The main principle is to determine whether the company does the rationalization of product space through periodic standardization of parts.

This grid area is composed of three maturity levels, which are based on the existence of a systematic procedure for eliminating unnecessary parts from the part portfolio and the extent to which this is done in the company:

- *Maturity level 1* – 'Never done'
  This is the basic (first) maturity level of the grid area. If the company is on this level, then rationalization with the goal of eliminating unnecessary product parts has never been conducted in the company.

- *Maturity level 2* – 'There is a systematic procedure to eliminate parts no longer needed and this procedure is done periodically for some part families'
  This is the next (second) maturity level of the grid area. On this level, the company possesses a systematic procedure that is used for eliminating unnecessary parts from the product portfolio. Furthermore, this procedure is enacted periodically for some of the part families, but not for all of them.

- *Maturity level 3* – 'There is a systematic procedure to eliminate parts no longer needed, and this procedure is done periodically for all part families'
  This is the highest (third) maturity level of this grid area. As with the previous (second) maturity level, there is a systematic procedure in the company for eliminating unnecessary parts from the product portfolio. However, at this maturity level, this procedure is conducted periodically on all (not just on some) of the part families.

Grid area 2 Standardization of parts: Day-by-day limitation of new parts introduction

This grid area is the second (of two) representing the part standardization in the maturity grid (the second one is GA1 - Figure 9). The basic idea is that through the work of design/production engineers and purchasing staff, attention is given to standardizing new parts introduced into production. Even more, the goal is to limit the introduction of new parts in order to prevent an increase in system complexity.

This grid area is composed of four maturity levels that are based on existing directions and software support for limiting the introduction of new parts into production:

- *Maturity level 1* – 'No attention is paid to parts proliferation by the organization, design/production engineers and purchasing staff'
  This is the basic (first) maturity level of the grid area. On this level, the organization, design engineers, production engineers and purchasing staff do not pay attention to parts proliferation in the product portfolio.
- *Maturity level 2* – 'No guidelines and no SW support exist, but design/production engineers and purchasing staff pay attention to parts proliferation'
  This is the next (second) maturity level of the grid area. On the one hand, as in the case of the previous level, on this level there are no directions for limiting the proliferation of new parts in production. Also, there is no software (SW) support for limiting the proliferation of new parts. On the other hand, on this maturity level, design engineers, production engineers and purchasing staff pay attention to parts proliferation and are making efforts to limit the introduction of new parts.
- *Maturity level 3* – 'Guidelines for design/production engineers and purchasing staff exist and are applied; no SW support'
  This is a higher (third) maturity level of the grid area. On this level, in comparison to the previous (second) one, there are directions for design/production engineers and purchasing staff and they are applied in practice. However, similar to the previous level, there is no SW support for limiting the proliferation of new parts.
- *Maturity level 4* – 'Guidelines for design/production engineers and purchasing staff exist and are applied very rigorously; SW support exists'
  This is the highest (fourth) maturity level of the grid area. As in the previous (third) maturity level, directions exist for design/production engineers and purchasing staff, and they are applied in practice. What separates this maturity level from all the previous ones in this grid area is that these directions are applied rigorously and they are supported with SW.

Grid area 3 Standardization of production sequences

This is the first grid area (of two) that represents the form postponement enabler (the second one is GA11 - Figure 9). The main idea is that with the work of design engineers, production engineers and the entire organization, attention is focused on introducing new production sequences (i.e. operation sequences[10]) into production. The goal is to limit the

[10] 'The *operation sequence* for a part is an ordering of the machines on which the part is sequentially processed' (Vakharia and Wemmerlöv 1990, 86).

proliferation of new production sequences and, as a result, to limit the increase in system complexity.

This grid area is composed of four maturity levels, which are based on the existence of a database of production sequences, rules for limiting the introduction of new production sequences and software support for limiting the introduction of new production sequences. The maturity levels are:

- *Maturity level 1* – 'No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers'
  This is the basic (first) maturity level of the grid area. On this level, no attention is paid to the proliferation of production sequences by the organization or the design and production engineers. There is no database of production sequences, so it is hard to reuse previously developed production sequences.

- *Maturity level 2* – 'It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)'
  This is the next (second) maturity level of the grid area. In comparison to the previous (first) maturity level, on this level there is a database of production sequences that is well organized, with production sequences organized in classes. This results in easier use of previously developed production sequences.

- *Maturity level 3* – 'It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes). There are rules and SW support to limit the introduction of new production sequences'
  This is a higher (third) maturity level of the grid area. As with the previous (second) maturity level, there is a database of production sequences that is well organized, with production sequences grouped in classes. This results in easier use of previously developed production sequences. In addition, at this maturity level, there are rules and SW support for limiting the introduction of new production sequences into the production system.

- *Maturity level 4* - 'It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes). There are rules and SW support to limit the introduction of new production sequences. We make production sequences that differentiate products as late as possible'

This is the highest (fourth) maturity level of the grid area. As in the previous (third) maturity level, there is a database of the production sequences that is well organized, with production sequences organized in classes, which results in easier use of previously developed production sequences. Also, there are rules and SW support for limiting the introduction of production sequences into the production system. In addition, at this maturity level, production sequences are designed so that products are differentiated as late as possible in the production process.

Grid area 4 Product modularization

This grid area presents product modularization. The main idea is to determine if the company develops its products (product families) on the principle of modularity, as well as to determine if product platforms based on the modules exist in the product portfolio.

This grid area is composed of four maturity levels, which are based on the degree of application of the modularity principle in the product portfolio (product families):

- *Maturity level 1* – 'No modularization at all'
  This is the basic (first) maturity level of the grid area. On this level, there is no application of product modularization in the product portfolio of the company.

- *Maturity level 2* – 'In some of our product families, the products have been thought about in such a way that each product function is performed by a specific chunk and does not need to interact with other chunks'
  This is the next (second) maturity level of the grid area. On this level, in some of the product families, products are developed on the principle of modularity. This means that for every function there is a specific chunk (module) and there is no need to interact with other chunks of the same product for execution of that function.

- *Maturity level 3* – 'We thought about all of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces'
  This is a higher (third) maturity level of the grid area. In comparison with the previous (second) maturity level, where the principle of modularity is used in some of the product families, on this level the principle of modularity for product development is used for all product families in the company's product portfolio.

- *Maturity level 4* – 'Our modules may have a longer life than single product families (product platforms exist)'

This is the highest (fourth) maturity level of the grid area. As in the previous (third) level, the principle of modularity is used for development of products for all product families in the product portfolio of the company. The main difference from the previous maturity level is in the life cycle of the developed modules, which is, in effect, longer than the single product families. This means that there are product platforms in the product portfolio of the company.

Grid area 5 Grouping of parts into families through a similarity-based classification system

This is the first grid area (of three) that represents the group technology enabler (the second is GA7 and the third is GA8 - Figure 9). This grid area presents one of the bases of the group technology enabler: the use of a classification system. The main principle is that a classification system should be created on the basis of part similarity in terms of shape, size and material. This sort of classification system leads to the formation of part groups that will be produced in similar production processes. This grid area is constituted of four maturity levels, which are based on the degree of implementation of a classification system:

- *Maturity level 1* – 'Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)'

  This is the basic (first) maturity level of the grid area. On this level, there is no classification system. Parts are not classified, thus we cannot speak about the use of a classification system that is typical for group technology implementation.

- *Maturity level 2* – 'Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through use of production and design engineers' experience; no structured classification system exists'

  This is the next (second) maturity level of the grid area. In comparison to the previous maturity level, the product parts are grouped in families through the use of the classification criteria based on similarity. These criteria are the shape, size and material from which the parts are made. As with part groups, part families are processed with similar production processes. However, on this maturity level, there is neither a structured nor a formalized classification system in the company. Parts classification is based solely on the experience of design and production engineers.

- *Maturity level 3* – 'Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through a structured manual classification system'
  This is a higher (third) level of the grid area. As on the previous level, parts are classified and part families are formed based on the principles of similarity. Similarities from the classification process are transferred to similarities in production processes. What differentiates this maturity level from the previous one is the existence of a structured classification system that is actively used in the company. The classification system is used manually and without any software support at this maturity level.

- *Maturity level 4* – 'Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through an automatic (SW) classification system'
  This is the highest (fourth) maturity level of the grid area. Product parts are grouped into part families on the basis of similarity criteria. Similarities in production processes are also present between product families. Classification processes are structured and automated, which is enabled by the use of classification software.

Grid area 6 Product space organized in clearly distinguished product families

This grid area represents the product platform development enabler and product families as a direct result of product platform application. The basic idea is to recognize the existence of product families, either modular or scaled (i.e. scale-based). This grid area is composed of four maturity levels, which are based on the existence of product families in the product portfolio, the existence of procedures for forming the product families, as well as the clarity of the distinctions between the various product families:

- *Maturity level 1* – 'No product families (modular and/or scaled) exist'
  This is the basic (first) maturity level of the grid area. At this level, there are no product families in the product portfolio, neither modular nor scaled.

- *Maturity level 2* – 'A portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. But, the clustering is not guided by design procedures'
  This is the next (second) level of the grid area. At this level, part of the product portfolio is composed of product families. Product families can be modular or scaled. Products are clustered into product families based on their functionality

and connectedness of their production processes. Design procedures for clustering products into product families do not exist at this maturity level.

- *Maturity level 3* – 'A considerable portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures. The distinction between product families is good, but can still be considerably improved'
  This is a higher (third) maturity level of the grid area. Compared to the previous maturity level, at this level a considerable part of the product portfolio is composed of product families. Products can be clustered in modular or scaled product families on the basis of product functions and connectedness of their production processes. What differentiates this maturity level from the previous one is the presence of design procedures for clustering products into product families, which results in good differentiation of product families. Still, there is a possibility for improvement in product family differentiation.
- *Maturity level 4* – 'The whole product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures that are deeply absorbed by the whole company's organization. Product families are clearly distinguished and do not overlap'
  This is the highest (fourth) maturity level of the grid area. Compared to the previous level, at this level the whole product portfolio is composed of product families. Products can be clustered in modular or scaled product families on the basis of product functions and the connectedness of their production processes. Design procedures for clustering products into product families exist. At this maturity level, design procedures for clustering products into product families are deeply accepted in the whole organization. Product families are clearly distinguished without overlaps.

Grid area 7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families

This grid area represents mixed model assembly lines, and at the same time is the second grid area (of three) that represents group technology (the first is GA5 and the third is GA8 - Figure 9). The main idea is to design the shop floor to achieve the highest speed and efficiency in processing the part/product families. This grid area is composed of four maturity levels, which are based on the existence of production structures that are capable of processing the families of parts/products to which they are dedicated. In other words, this grid area looks at the existence of the product-based flow, the manufacturing and assembly cells, as well as mixed-model assembly lines on the company shop floor:

- *Maturity level 1* – 'Machines are clustered on the shop floor based on their functional similarity'
  This is the basic (first) maturity level of the grid area. At this level, machines are clustered according to their functional similarities, thus on the basis of processes (process approach).

- *Maturity level 2* – 'Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated'
  This is the next (second) maturity level of the grid area. Compared to the previous (first) maturity level, at this level, machines and assembly lines are capable of processing different parts/products with similar efficiency. Machines and assembly lines are clustered on the basis of the part/product families to which they are dedicated.

- *Maturity level 3* – 'Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated. The positioning and organization of the machines/assembly stations minimizes the time that the parts/products take to pass through autonomous production units'
  This is the higher (third) maturity level of the grid area. As in the previous maturity level, machines and assembly lines are capable of processing different parts/products with similar efficiency. Machines and assembly lines are clustered according to the part/product families to which they are dedicated. In addition, machines and assembly lines are clustered in a way that minimizes the time parts/products spend in manufacturing cells.

- *Maturity level 4* – 'Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated. The positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through autonomous production units. A system is in place to continuously improve the speed and efficiency of the autonomous units in processing the parts/product families'

This is the highest (fourth) maturity level of the grid area. As in the previous (third) maturity level, machines and assembly lines are capable of processing different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated. Furthermore, machines and assembly lines are clustered in a way that minimizes the time the parts/products spend in manufacturing cells. Compared to the previous (third) maturity level, at this level there is a system for continuous advancement of the speed and efficiency of manufacturing cells that are processing part/product families.

Grid area 8 Low and continuously reduced set-up times

This grid area represents SMED, and is the third grid area (of three) that represents group technology - use of group tools (the fist one is GA5 and the second one is GA7 - Figure 9). The main idea is the application of the system for continuous lowering of the set-up times. This grid area is composed of three maturity levels, which are based on the level of application of SMED, as well as on the application of the special tools dedicated to part families and/or product families (group tools):

- *Maturity level 1* – 'Set-up times are very long; no systematic reductions of set-up times are being applied'

  This is the basic (first) maturity level of the grid area. At this level, no systematic reduction of set-up times in the production system is being applied. As a consequence, set-up times are very long.

- *Maturity level 2* – 'Set-up times are neither long nor short; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) or by application of special tools dedicated to part families and/or product families'

  This is the next (second) maturity level of the grid area. Set-up times at this level are neither long nor short. At this level, the reduction of set-up times is achieved through continuous analysis and changes in:
  - The technology used – which can imply use of machines with low set-up times, as well as fasteners, positioning aids, standardized tools, etc.
  - Organization – which can imply standardization of set-up procedures, using offline set-up, etc.
  - Application of special tools dedicated to part families and/or product families (group tools)

- *Maturity level 3* – 'Set-up times are very short; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) and by application of special tools dedicated to part families and/or product families'
  This is the highest (third) maturity level of the grid area. At this level, set-up times are very short. Also at this level, set-up times are reduced through continuous analysis and changes in three areas:
  - The technology used – which can imply the use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.
  - Organization – which can imply standardization of set-up procedures, using offline set-up and so on.
  - Application of special tools dedicated to part families and/or product families (group tools)

Grid area 9 Technical configurator

This grid area is the first (of two) representing IT-based product configuration (the second one is GA10 - Figure 9). The main idea of this grid area is the development of a technical configurator that is capable of automatically generating BOMs for all possible product variants. This grid area is composed of four maturity levels, which are based on the existence, the mode of implementation, and the scope of technical configurator use in the company:

- *Maturity level 1* – 'Bills of materials (BOMs) and production sequences (if present) are manually defined by production engineers, eventually copied and modified from similar BOMs/production sequences'
  This is the basic (first) maturity level of this grid area. At this level there is no technical configurator. The BOMs and production sequences (if they exist at all) are manually defined. At this level, it is possible that BOMs and production sequences are copied or modified from similar BOMs/production sequences.

- *Maturity level 2* – 'For some product families, BOMs and/or production sequences are automatically generated for a lot of possible variants of the product family, starting from the provided product specifications'
  This is the next (second) maturity level of the grid area. Compared to the previous (first) maturity level, at this level for a large number of product variants in some product families, BOMs and/or production sequences are automatically generated

- *Maturity level 3* – 'For almost all product families, BOMs and/or production sequences are automatically generated for most of the possible variants of the product family, starting from the provided product specifications'
  This is a higher (third) maturity level of the grid area. Compared to the previous level, where BOMs/production sequences are automatically generated only for some product families, at this level BOMs and/or production sequences are automatically generated for almost all product families and the highest possible number of product variants in those product families.

- *Maturity level 4* – 'BOMs and production sequences (if needed) are automatically generated for almost all possible variants, starting from the provided product specifications'
  This is the highest (fourth) maturity level of the grid area. Compared to the previous (third) maturity level, at this level, BOMs and production sequences (if needed) are automatically generated for all product families and for almost all product variants of those product families.

Grid area 10 Sales configurator

This grid area is the second (of two) representing IT-based product configuration (the first one is GA9 - Figure 9). The main idea of this grid area is the development of a sales configurator that would enable customers, salesmen and the technical staff responsible for sales to choose all product characteristics and control the compatibility of these characteristics. This grid area is composed of four maturity levels, which are based on the existence, mode of implementation and scope of sales configurator use in the company:

- *Maturity level 1* – 'Customers, salesmen and the technical-sales employees do not have any structured support in choosing all the specific characteristics of the product and in controlling their compatibility'
  This is the basic (first) maturity level of the grid area. At this maturity level there is no sales configurator. Further, at this level there is no structured support for the choice of product characteristics and control of their compatibility, which could be used by customers, salesmen and technical-sales employees responsible for sales.

- *Maturity level 2* – 'Customers, salesmen and the technical-sales employees have structured support (but do not have any SW support) in choosing all the specific characteristics of the product and in controlling their compatibility'
  This is the next (second) maturity level of the grid area. Compared to the previous (first) maturity level, at this level there is structured support for choosing product

characteristics and controlling their compatibility, which customers, salesmen and the technical-sales employees responsible for sales can use.

- *Maturity level 3* – 'Customers and/or salesmen and/or technical-sales employees use SW that supports them in choosing the main characteristics of the products and in controlling their compatibility (at least for the most important product families)'
  This is a higher (third) maturity level of the grid area. As in the previous (second) maturity level, there is structured support for choosing product characteristics and controlling their compatibility, which customers, salesmen and the technical-sales employees responsible for sales can use. Compared to the previous level, at this level SW support is available for choosing the main product characteristics and for compatibility control of those characteristics, at least for the most important product families.
- *Maturity level 4* – 'Customers and/or salesmen use SW that supports them in choosing all the characteristics of the products and in controlling their compatibility (for all or almost all of the product families)'
  This is the highest (fourth) maturity level of the grid area. As in the previous maturity level there is structured and SW support for choosing product characteristics and controlling their compatibility, which customers, salesmen and the technical-sales employees responsible for sales can use. Compared with the previous maturity level, at this level software support is used for choosing all product characteristics and for compatibility control of those characteristics for all, or almost all product families.

Grid area 11 Keeping stocks at optimal levels

This is the second (of two) grid areas representing form postponement (the first one is GA3 - Figure 9). It is also the first grid area (of two) representing virtual build to order (the second one is GA12 - Figure 9). The main idea of this grid area is the development of a system for production planning and control that is capable of providing an optimal level of service to the next phase in the production process, assembly and product delivery to the customer while maintaining the level of the working capital (finished products, modules, components, parts and raw materials) at an optimum level. Thus, this grid area deals with the trade-off between maximum service and the minimum amount of working capital under conditions of high product variety (i.e. mass customization). This grid area is composed of four maturity levels, which are based on the existence of a production planning and control system; the level of service provided to the each subsequent phase of production, assembly and product delivery; as well as the degree of working capital engagement:

- *Maturity level 1* – 'We do not have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) and maintain working capital (finished products, modules, components, parts and raw materials) at an acceptable level'
  This is the basic (first) maturity level of the grid area. At this level the system for production planning and control cannot provide an acceptable level of service to the subsequent process stage, and cannot maintain the working capital at an optimal level.
- *Maturity level 2* – 'We have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an acceptable level'
  This is the next (second) maturity level of the grid area. Compared to the previous (first) level, at this level there is a system for production planning and control that can provide an acceptable service level at the subsequent stage. Furthermore, this system maintains the working capital at an acceptable level.
- *Maturity level 3* – 'We have a production planning and control system that can assure a very good service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at a very low level'
  This is a higher (third) maturity level of the grid area. Compared to the previous (second) maturity level, at this level there is a system for production planning and control which can provide a very good service level at the following process stage. Furthermore, compared with the previous level, this system maintains the working capital at a very low level.
- *Maturity level 4* – 'We have a production planning and control system that can assure an optimal service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining

working capital (finished products, modules, components, parts and raw materials) at an optimal level'
This is the highest (fourth) maturity level of the grid area. Compared to the previous (third) maturity level, at this level there is a system for production planning and control that can provide an optimal level of service at the subsequent process stage. Furthermore, when compared with the previous level, this system maintains the working capital at an optimal level.

Grid area 12 Sophisticated and dependable supports for determining available to promise

This is the second grid area (of two) representing virtual build to order (the first one is GA11 - Figure 9). The main idea of this grid area is the development of a sophisticated and reliable support system for determining available to promise. Thus, the goal is to enable the production system to determine when a product (or a product variant) that was promised to the customer will be available for delivery under conditions of high product variety (i.e. mass customization). In addition, the goal is to introduce a system that will enable changes in the product configurations that are already in production without increasing the product price and without influencing the level of service provided to the customer. This grid area is composed of four maturity levels, which are based on the existence of a support system for determining the availability to promise, a system for enabling changes in product configurations that are already in the production, as well as the degree of implementation of these two systems:

- *Maturity level 1* – 'It is difficult for us to say whether or not the products that are available in the finished products stocks or that are in production are available to promise'
  This is the basic (first) maturity level of the grid area. At this level, the company is not capable to determine whether or not the finished products in stock or the semi-finished products in production are available to promise to the customer. In addition, the company is not able to determine the exact date of product delivery to the customer. Thus, company employees often estimate the delivery time, which is often wrong.
- *Maturity level 2* – 'If we look for a certain quantity of a given finished product, we know how much of it is available to promise in our stocks and how much is available to promise in production, but in the latter case, we are not really dependable regarding when they will be available in the warehouse. If the product is not yet

launched into production, we apply some fixed lead times for the promise that are common for several products'
This is the next (second) maturity level of the grid area. Compared to the previous (first) maturity level, at this level a system exists that enables a certain determine of how much of the demanded quantities are available for promise to the customer from the stocks of finished products, as well as among products that are still in the production process. However, if the products are still in the production process, the company is not always able to determine the exact moment the product will be in the stock. As for products for which production has not yet started, an average delivery time that is common for a number of different products is applied for the promise of these products to the customer.

- *Maturity level 3* – 'We know exactly how much of each product is available to promise both, in our stocks and in production and, in the latter case, we are very dependable regarding when the product will be available in the warehouse'
  This is a higher (third) maturity level of the grid area. As for the previous (second) maturity level, a system exists that enables positive determination of how much of the demanded quantities are available for promise to the customer from the stocks of finished products, as well as from among products that are still in the production process. Compared to the previous level, at this level the company is capable of determining with a high level of certainty when the product will come to the warehouse (stocks).

- *Maturity level 4* – 'We are able to tell exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer'
  This is the highest (fourth) maturity level of the grid area. As at the previous (third) level, a system exists that enables positive determination of how much of the demanded quantities are available for promise to the customer from the stocks of finished products, as well as from among products that are still in the production process. This system also enables determination of the exact moment of arrival of the product to the warehouse (stocks). Compared to the previous level, this level has the possibility to execute changes to product configurations that are already in production. In this way, the company is able to promise customized products with

the earliest possible delivery date in a reliable way and without incurring additional costs or reducing the service delivered to the customer.

2.4 Observational evaluation of the MC maturity grid

The MC maturity grid has been developed through the use of literature, analytical reasoning and an iterative interview process with managers, consultants and academics. The development of the MC maturity grid started from the literature review findings, namely the identified MC-IG properties and the eight MC enablers derived from the relevant literature.

The MC maturity grid (Figure 11) is intended for use as an assessment tool to determine the MC maturity level of SMEs. Furthermore, it is expected that the MC maturity grid could be used as a decision support tool for SMEs pursuing MC. More specifically, to the SME that applies it, it is expected that the grid will enable certain benefits:

1. Learn about the grid areas of the MC maturity grid
2. Learn about the maturity levels of the various grid areas
3. Gain an awareness about the status of the company in the various grid areas
4. Involvement of employees in brainstorming about the possible advancements of the company in the various grid areas (The maturity grid does not provide answers, but it provides a number of stimuli that allow employees to understand which advancements are applicable and useful and which ones are not useful or are too advanced for their company)
5. Identify advancements at the various levels that are meaningful for the current MC status of the company
6. Prioritize MC improvements

In the following two subsections (subsections 2.4.1 and 2.4.2), I will first develop a procedure for implementation of the MC maturity grid in seven steps (section 2.4.1); and second, I will augment the developed implementation procedure with some other steps (leading to a final nine steps) in order to adapt it to the assessment of the MC maturity grid (subsection 2.4.2). Although the repetition of some of the steps in the two procedures may seem redundant, the choice has been made to show the complete procedures in order to achieve higher clarity in the presentation.

2.4.1 Procedure for use of the MC maturity grid

In order to reach the expected benefits from the application of the MC maturity grid, a procedure for its use was developed (Figure 12). The procedure is composed of seven steps (Figure 12), namely:

1) **Introduction to use of the MC maturity grid** – The goal of this step is to provide only the basic insights in the MC maturity grid, not revealing the whole purpose

of the artefact or its presumed benefits. On the one hand, this kind of representation can lead to slight confusion of the company personnel. On the other hand, this approach offers the company staff an opportunity to obtain the benefits of the MC maturity grid by themselves. In this way, a short introduction to the maturity grid application without explaining the whole grid too deeply is justified.

2) **Explanation of the grid area** – The goal of this step is to present the terminology (i.e. the concepts/terms/explanations provided in subsection 2.3.2) used in the grid to the company staff. This presentation, which could consume more or less time depending on the participants' background and experience, is important for focusing the workshop group that is using the maturity grid. In effect, this can prevent the case in which every member of the group interprets a specific grid area in his/her own way based on his/her background and experience.
3) **Explanation of every maturity level in the grid area** – The goal of this step is to deepen the company staff's understanding of every maturity level in the grid area that is being analyzed. It is highly important to go through every maturity level in the specific grid area in order to make sure company staff has understood all of the maturity levels. This step of the procedure for use of the grid, which could consume more or less time depending on the participants' background and experience, is important not only for successful realization of the next step, but also for the success of the whole implementation procedure.
4) **Determining the maturity level of the company in the grid area** – The goal of this step is to determine the maturity level of the company in the given grid area. The collection of company positions in all of the 12 grid areas forms the MC maturity level of the company.
5) **Generating new ideas for advancement in the grid area** – After the maturity level of the company in a grid area has been determined and the overall MC maturity level of the company has been determined, the group is ready to generate concrete ideas for advancement in every grid area. The goal of this step is to generate ideas that are feasible and compatible for the company by the reasoning of the company's staff. Ideas are to be generated taking into account the current maturity level of the company in specific grid areas. These kinds of ideas will not be imposed, but, since they come from the staff themselves, the ideas are more likely to be close to the mind of company and have a greater chance to be applied.
6) **Prioritizing the generated ideas** – After the ideas for advancements have been generated, it is necessary to determine the priority of these ideas in order to create a clear plan for MC implementation in the company. The company staff

determines the priority of the ideas with the help of a moderator who strives only to clearly define what the company staff is saying. Thus, the goal of this step is to define the priority assigned by the company staff to every generated idea. Special attention should be given to ensuring that the employee responsible for implementing an idea in practice plays a leading role in determining the priority of that initiative. Thereby, the priority of an initiative takes into account the benefits (both short-term and long-term), the efforts needed for realization (capital, man-hours, employee resistance to change), as well as other impacts (e.g. personal problems at work), which are regarded as important by the employee that is responsible for implementing the idea.

7) **Generating the implementation plan** – When a priority level has been assigned to every idea, there is a need to generate a plan for implementing these ideas in practice. The goal of this step is to determine the sequence for the generated initiatives based on the priorities perceived by the company staff.

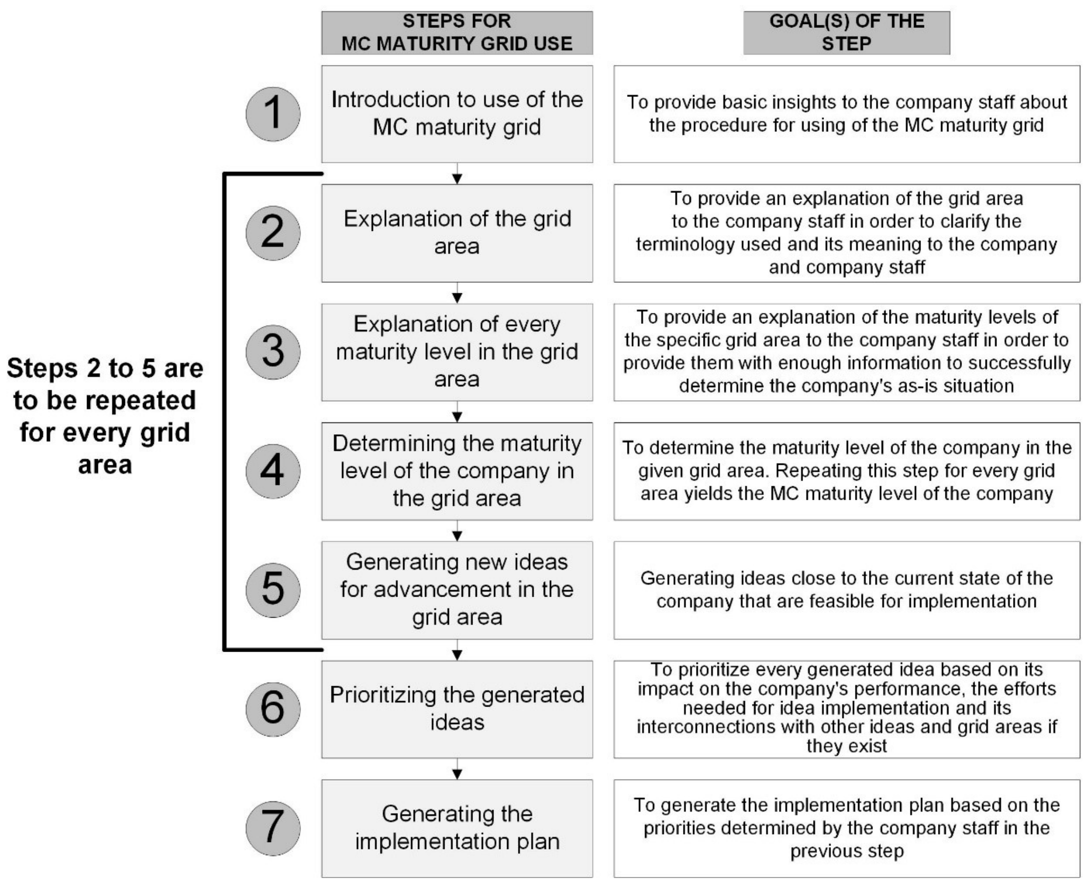


Figure 12. Procedure for use of the MC maturity grid

2.4.2 Procedure for evaluation of the MC maturity grid

The procedure for use of the MC maturity grid (Figure 12) had to be slightly modified in order to evaluate the MC maturity grid under industry conditions. This was done by adding new steps or slightly altering existing steps in the procedure for use of the MC maturity grid. As a result, the procedure for MC maturity grid evaluation is as follows (Figure 13):

1) **Introduction to use of the MC maturity grid** – NO CHANGES
2) **Explanation of the procedure for MC maturity grid evaluation** – This step is done by the research team (workshop moderators). The procedure for maturity grid evaluation is briefly explained to the company staff. The reason for this is the same as the reason for the short introduction to the use of the MC maturity grid: the intention is to leave the conclusions to the workshop participants, and not to dictate conclusions.
3) **Evaluation of the grid areas** – The goal of this step is twofold. The first goal is to present the terminology (i.e. the concepts/terms/explanations provided in subsection 2.3.2) used in the grid to the company staff. This presentation, which could consume more or less time depending on the participants' background and experience, is important for focusing the workshop group that is using the maturity grid. In effect, this prevents the case in which every member of the group, based on his/her background and experience, interprets a specific grid area in his/her own way. The second goal of this step is to determine if the number of grid areas and the understandability of the grid areas are suitable for the company staff. Specifically, the step is aimed at understanding:
    - **The suitability of the number of grid areas** – The company staff will be asked to discuss whether the number of grid areas is adequate, or too small or too large. This refers mostly to the size and robustness of the MC maturity grid and is to be treated solely as a personal view of the company staff, but there is a need to record this data anyhow.
    - **The understandability of the grid area title** – Discussion of every grid area title and the understandability of the meaning of the title to the company staff.
4) **Evaluation of the maturity levels** – The goal of this step is twofold. The first goal is to deepen the company staff's understanding of every maturity level of the grid area that is analyzed. It is highly important to go through every maturity level of the specific grid area in order to make sure that company staff has understood all of the maturity levels. This step of the evaluation procedure, which could consume

more or less time depending on the participants' background and experience, is important not only for successful realization of the next step, but also for the success of the whole implementation procedure. The second goal of this step is to evaluate the suitability of the maturity levels and the clarity of the descriptions of maturity levels:

- **Suitability of the maturity levels for every grid area** is to be evaluated in the discussion with company staff in order to determine if the levels are adequate from the staff's point of view. If the maturity levels are not perceived as adequate, notes are taken and changes in the MC maturity grid are to be discussed later.
- **Clarity of the maturity levels descriptions** – This evaluation is done in parallel with the evaluation of the suitability of the maturity levels. If the company staff has a problem understanding the cell text, then we can conclude that there is a problem with the clarity, and how it can be improved will be discussed.

5) **Determining the maturity level of the company in the grid area** – NO CHANGES
6) **Generating new ideas for advancement in the grid area** – NO CHANGES
7) **Prioritizing the generated ideas** – NO CHANGES
8) **Generating the implementation plan** – NO CHANGES
9) **Determining the overall suitability and significance of the MC maturity grid** – After the whole procedure has been conducted and every grid area has been discussed, discussion of the whole MC maturity grid is to be undertaken. The aim of this discussion is to gain company feedback regarding:
   - The overall usefulness of the MC maturity grid
   - Some new insights the MC maturity grid has provided to the company staff
   - Thoughts about the future applicability of the MC maturity grid in their company

This part of the evaluation is fully open for discussion from the company staff and their suggestions about how the MC maturity grid could be improved so it is more suitable for their use.

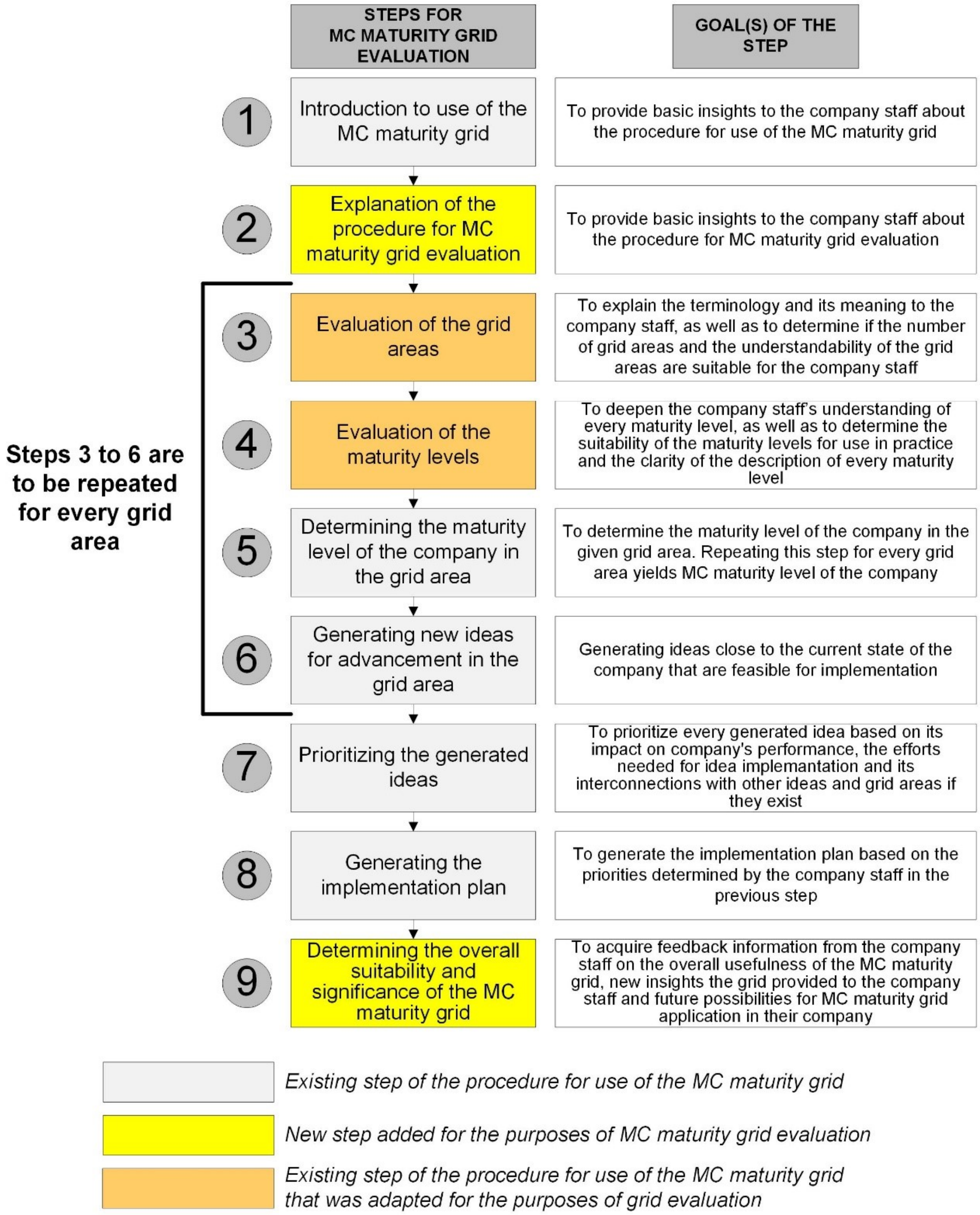


Figure 13. Procedure for MC maturity grid evaluation

The evaluation of the MC maturity grid was done using the observational evaluation method (Hevner et al. 2004), that is, the use of the developed artefact (i.e. the grid) in the actual context following the proposed procedure for MC maturity grid evaluation (Figure 13).

The purpose of the observational evaluation was to determine if the two defined success criteria in the planning phase were met:

- For success criterion 1 (*MC maturity grid is understandable to practitioners (usability)*), the goals were to:
    - Check if the grid in general, the grid areas and the maturity levels are understandable and thus usable for SMEs
    - Criticize the MC maturity grid from the SME point of view, with a focus on finding inadequacies in the maturity grid and its application procedure
    - Discuss possible changes and upgrades to the MC maturity grid with industry engineers
- For success criterion 2 (*MC maturity grid can successfully assess the MC level of SMEs (usefulness)*), the goal was to:
    - Demonstrate the capability of the MC maturity grid to assess the MC maturity level of a company by determining the MC maturity level of the company in each grid area.

The research team agreed to open the discussion on every topic the company staff was ready to talk about regarding the MC maturity grid but to have a couple of predetermined milestones for testing:

- Use the model in actual conditions following the procedure for evaluation of the MC maturity grid (Figure 13)
- Observe and record:
    - All that is asked and said by the participants
    - The time devoted to various activities
    - Interactions, both between researchers and participants, and among the participants
- Ask at the end what the participants gained from the experience
- Conduct an analysis of the gathered data

2.4.3 MC maturity grid observational evaluation in Metalmeccanica SPA

Although in this research phase only the core part of the MC-IGs is developed, the expected outcome of MC maturity grid implementation is a clear plan of implementation activities that can be presented to the company's top management. This implementation plan should be pursued in order to move towards MC.

In order to find out if applying the MC maturity grid will lead to the expected outcome, an observational evaluation was done in two SMEs, one from the manufacturing sector and one from the service sector. With two company cases analyzed, the evaluation focuses on depth rather than on breadth. The results of these evaluations follow.

2.4.3.1 Metalmeccanica SPA company overview

Metalmeccanica SPA[11] is a privately owned Italian SME established in 1982. At first, the company was established as a trading company that traded mechanical spare parts for industry. A few years later, the company started its own production and has been in constant expansion, both in the terms of the product assortment and the quantities of produced and traded goods.

At the moment of evaluation of the MC maturity grid, Metalmeccanica SPA had over 100 employees and a turnover of 35 million euro per year. The company buyers are mostly from Northern Italy, but the company is expanding its market to Eastern Europe, China and Japan.

The company product assortment is composed mainly from hydraulic power units, assembly lines and high-pressure flexible hoses for industry (Figure 14).

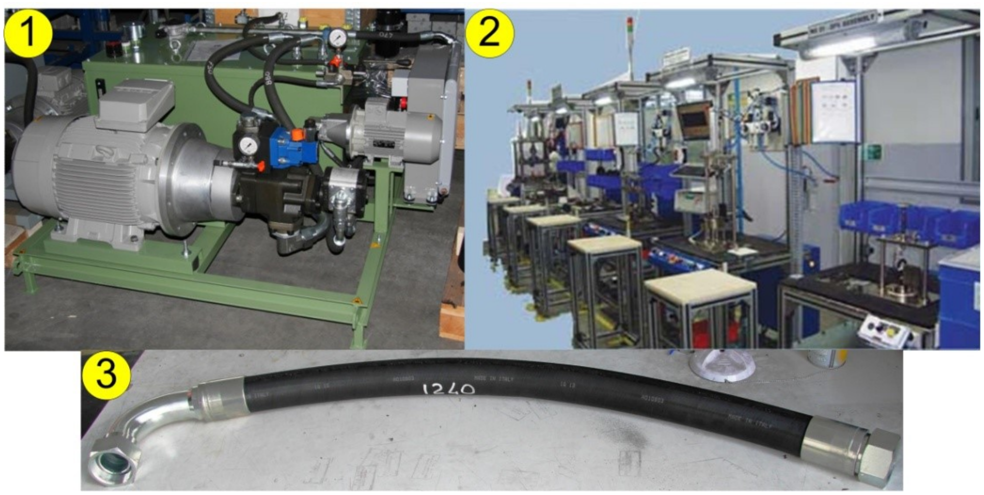


Figure 14. Product assortment of Metalmeccanica SPA: 1) hydraulic power units, 2) assembly lines and 3) high-pressure flexible hoses for industry

One of the main characteristics of these three product lines is their configurability, followed by a high variety in production and assembly. In addition to this variety, the company makes efforts to satisfy its customers and to realize product configurations that suit the different needs and requests of the customers. Incidentally, this is one of the trademarks for which Metalmeccanica SPA is known in its industrial sector.

[11] 'Metalmeccanica SPA' is a fake name used to keep confidentiality of the company data

This variety and readiness to answer almost every customer request causes problems in organizing the production, planning delivery time and scheduling production. Thus, the company applies product customization, but it does not do it in an organized way by applying different MC enablers. Instead, the company applies product customization through high reliance on the experience of the company owner and experienced company engineers.

An awareness of the problems the company has with customized production, as well as an openness to innovation and a constant need for advancement has led the company to agree to conduct the MC maturity grid evaluation on its product assortment. Further, the company did not formulate any expectations as far as the MC maturity grid application is concerned. Nevertheless, since the company had had positive interactions with the university in the past that led to significant reductions in warehouse expenses and stock size, it was ready to undergo the MC maturity grid evaluation procedure in order to discover whether it was possible to achieve better effects in its production.

2.4.3.2 Workshop group for MC maturity grid evaluation - Metalmeccanica SPA

The group for the MC maturity grid evaluation was composed of six persons. Four of them were company representatives and two were university members.

The company representatives from Metalmeccanica SPA were:

- A logistics and operations manager
- A sales/marketing manager (with responsibility for product management, too)
- A design engineer for the family of hydraulic power units (HPU)
- A design engineer for the family of assembly lines

Notably, the group is mostly made up of mechanical engineers, some of them with an engineering management master's degree.

The workshop group was selected on the basis of the expected MC maturity grid evaluation needs. The team was composed of engineering staff, covering the managerial, production, design and purchasing functions of the company. Therefore, the company group was composed of the people responsible for making changes in product and process design and organizational aspects of the business. In reality, this is the group that would be responsible for implementing changes identified through MC maturity grid use.

The research team that did the evaluation was composed of two persons:

- A PhD candidate (Nikola Suzić) and
- A mentoring professor (Cipriano Forza).

2.4.3.3 Overview of the process of MC maturity grid evaluation in Metalmeccanica SPA

The MC maturity grid was evaluated with the group of six workshop participants, four company staff and a research team of two persons. The grid evaluation started with a short introduction to the MC maturity grid, followed by a discussion about every grid area. An overview of the sequence of evaluation of every grid area is provided in Table 19.

Table 19. Overview of the MC maturity grid evaluation sequence in Metalmeccanica SPA

Temporal sequence	Number of evaluation procedure step (Figure 13)	Evaluation step/Grid area
1	1	Introduction to use of the MC maturity grid
2	2	Explanation of the procedure for MC maturity grid evaluation
3	3, 4, 5 and 6	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed
4	3, 4, 5 and 6	2 Standardization of parts: Day-by-day limitation of new parts introduction
5	3, 4, 5 and 6	3 Standardization of production sequences
6	3, 4, 5 and 6	11 Keeping stocks at optimal levels
7	3, 4, 5 and 6	12 Sophisticated and dependable supports for determining available to promise
8	3, 4, 5 and 6	4 Product modularization
9	3, 4, 5 and 6	6 Product space organized in clearly distinguished product families
10	3, 4, 5 and 6	5 Grouping of parts into families through similarity-based classification system
11	3, 4, 5 and 6	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families
12	SKIPPED	8 Low and continuously reduced set up times
13	3, 4, 5 and 6	9 Technical configurator
14	3, 4, 5 and 6	10 Sales configurator
15	9 – Part 1	Determining the overall suitability and significance of the MC maturity grid – *Part 1 Discussion of the experience of MC maturity grid evaluation after evaluation of every grid area*
16	7	Prioritizing the generated ideas
17	8	Generating the implementation plan
18	9 – Part 2	Determining the overall suitability and significance of the MC maturity grid – *Part 2 Discussion of the prioritizing ideas step and the generating an implementation plan step*

19	9 – Part 3	Determining the overall suitability and significance of the MC maturity grid – *Part 3 Final discussion on the MC maturity grid's suitability and significance*

Table 19 shows that evaluation of the grid areas did not strictly follow the order of the grid areas in the MC maturity grid. The sequence of evaluation was changed ad hoc because the company staff was providing comments leading to the conclusion that there should be a change in the sequence of evaluation and discussion should be led in another way. Following this reasoning, grid area 11 (Keeping stocks at optimal levels) and grid area 12 (Sophisticated and dependable supports for determining available to promise) were evaluated before grid area 4 (Product modularization).

2.4.3.4 Results of the observational evaluation – Metalmeccanica SPA

In Table 20, the grid areas are listed by the amount of time it took for them to be successfully processed by the workshop participants. The table also shows three clusters of grid areas that were created based on the time spent on each of the grid areas.

Table 20. Grid areas listed according to the amount of time it took to process them

Time slot	Grid area	Total time spent on grid area (min.)	Grid area clusters
1	11 Keeping stocks at optimal levels	53:00	Grid area cluster 1 – grid areas to which the group gave most attention Total time spent: 1 h 59 min 30 sec Average time per grid area: 29,8 min
2	2 Standardization of parts: Day-by-day limitation of new parts introduction	26:00	
3	4 Product modularization	21:00	
4	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	19:30	
5	3 Standardization of production sequences	17:30	Grid area cluster 2 – grid areas to which the group gave medium attention Total time spent: 43 min 30 sec Average time per grid area: 14,5 min
6	10 Sales configurator	15:00	
7	12 Sophisticated and dependable supports for determining available to promise	11:00	

8	6 Product space organized in clearly distinguished product families	9:00	Grid area cluster 3 – grid areas to which the group gave least attention Total time spent: 33 min Average time per grid area: 6,6 min
9	5 Grouping of parts into families through a similarity-based classification system	7:00	
10	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	7:00	
11	9 Technical configurator	6:00	
12	8 Low and continuously reduced set-up times	4:00	

Table 20 lists all of the grid areas based on the total time spent for discussion of each grid area. On the one hand, the amount of time spent on explaining each grid area to the company staff was similar for all of grid areas, varying from 1 to 3 minutes (2 minutes on average). On the other hand, the amount of time workshop participants spent on each grid area varied drastically, from 4 minutes for grid area 8 (Low and continuously reduced set-up times), to almost an hour (53,5 minutes) for grid area 11 (Keeping stocks at optimal levels). The conclusion for grid area 8 was that this grid area had no real relevance for company performance. In light of the short analysis, discussion of this grid area was completed very quickly. However, on the grid areas from cluster 1 (Table 20), participants took their time, dedicating an average of almost 30 minutes for processing every grid area. This clearly signals that these are the grid areas of most importance to the company at this moment.

It seems that the amount of time spent discussing a specific grid area indicates the importance of that grid area to the company, since the analysis showed that there is almost complete correspondence between the time spent on discussing a specific grid area and its priority in the generated implementation plan—except for the sales configurator grid area (Table 22). Thus, based on the time spent to process them, it can be presumed that keeping stocks at optimal levels, standardization of parts (both grid areas) and product modularization are the most critical areas to be worked on from the view point of the company staff. The other problems the company is facing are addressing production sequences standardization, sales and delivering available to promise. The cluster of grid areas on which the least time was spent in the evaluation addresses product families, part families, shop floor organization, the technical configurator and reducing the set-up times in production.

In the following part of the chapter, the results of each evaluation step from the procedure for MC maturity grid evaluation (Figure 13) are presented.

1) **Introduction to use of the MC maturity grid** – NOTHING TO REPORT

2) **Explanation of the procedure for MC maturity grid evaluation** – NOTHING TO REPORT

3) **Evaluation of the grid areas**

- **The suitability of the number of the grid areas**
  The issue of the size of the MC maturity grid was not argued by the company staff. Although the evaluation process took a longer time than expected, no comments were made in terms of the grid being too big or hard to use because of the size. In this regard, the evaluation proved that the MC maturity grid is not too big.
- **The understandability of the grid area titles**
  No objections were made to the titles of any of the 12 grid areas. The titles of the grid areas were well understood and well received by the company staff. Notably, the explanation provided by the moderators (research team) as the company staff was reading the grid area titles helped convey the meaning of the grid area titles.

4) **Evaluation of the maturity levels**

Researchers noticed that, while reading, company staff encountered difficulties understanding the meaning of the text that explains the maturity levels. In order to facilitate understanding, the research team had to shorten the explanations and focus on the differences between the maturity levels. So, in order to keep the discussion focused on a specific grid area, the research team took the role of moderators. These two additional actions helped substantially and the company staff had no problem using the grid. It can be concluded that the grid should be used under the guidance of a moderator and with several interactions between the moderator and company staff.

This part of the evaluation dealt with:

- **Suitability of the maturity levels for every grid area**
  In general, the maturity levels of the grid areas were found suitable for use. However, in some cases (1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed; 3 Standardization of production sequences and 10 Sales configurator), company staff identified positions in between the levels as being right for them. These 'in-between

positions' will be discussed later in the results overview. Further, in one case (8 Low and continuously reduced set-up times), maturity levels were not discussed in detail because the company staff concluded that this grid area would not have an impact on their production performances, so it was skipped.

- **Clarity of the maturity levels descriptions**
  In general, the descriptions of maturity levels were clear to the company staff, needing short introductions to the grid areas. Some difficulties were encountered only in grid area 6 'Product space organized in clearly distinguished product families'. Finally, for grid area 8 'Low and continuously reduced set-up times', the clarity of the maturity levels descriptions was not discussed in detail because the company staff concluded that this grid area has no impact on their production performances.

5) **Determining the maturity level of the company in the grid area**

The assessed MC maturity level of the company that was determined during the MC maturity grid evaluation is presented in this part of the evaluation overview.

Soon after the start of the evaluation procedure in Metalmeccanica SPA, the issue of determining the MC maturity level of the company arose. This issue arose due to the fact that three distinct product families (hydraulic power units, flexible hoses and assembly lines) exist in the product assortment of the company. To solve this issue, after a short discussion within the workshop group, an agreement was reached that, since company staff perceive clear differences between product families, the MC maturity level should be determined for each product family separately instead of determining a single MC maturity level for the whole SME. The MC maturity levels that were determined are provided in Figure 15 (for the hydraulic power units product family), Figure 16 (for the flexible hoses product family) and Figure 17 (for the assembly lines product family).

Differences in the MC maturity levels that can be perceived in Figure 15, Figure 16 and Figure 17 clearly show that the MC maturity level can vary significantly in one company depending on which part of the product assortment (product family) is analyzed. In fact, the observational evaluation done at Metalmeccanica SPA has shown that, in order to determine a clear MC maturity level, the assessment should be done at the product family level.

Grid area =>	1	2	3	4
Maturity level ‖ V	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Product modularization
1	Never done	No attention is paid to parts proliferation by the organization, design/production engineers and purchasing staff	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	No modularization at all
2	There is a systematic procedure to eliminate parts no longer needed and this procedure is done periodically for some part families	No guidelines and no SW support exist, but design/production engineers and purchasing staff pay attention to parts proliferation	It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	In some of our product families, the products have been thought about in such a way that each product function is performed by a specific chunk and does not need to interact with other chunks
3	There is a systematic procedure to eliminate parts no longer needed, and this procedure is done periodically for all part families	Guidelines for design/production engineers and purchasing staff exist and are applied; no SW support	+ there are rules and SW support to limit the introduction of new production sequences	We thought all of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces
4		Guidelines for design/production engineers and purchasing staff exist and are applied very rigorously; SW support exists	+ we make production sequences that differentiate products as late as possible	Our modules may have a longer life than single product families (product platforms exist)

Grid area =>	5	6	7	8
Maturity level ‖ V	Grouping of parts into families through a similarity-based classification system	Product space organized in clearly distinguished product families	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	Low and continuously reduced set-up times SKIPPED
1	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	No product families (modular and/or scaled) exist	Machines are clustered on the shop floor based on their functional similarity	Set-up times are VERY LONG; no systematic reductions of set-up times are being applied
2	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through use of production and design engineers' experience; no structured classification system exists	A portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. But, the clustering is not guided by design procedures	Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated	Set-up times are NEITHER LONG NOR SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) or by application of special tools dedicated to part families and/or product families
3	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through a structured manual classification system	A considerable portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures. The distinction between product families is good, but can still be considerably improved	+ the positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through autonomous production units	Set-up times are VERY SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up etc.) and by application of special tools dedicated to part families and/or product families
4	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through an automatic (SW) classification system	The whole product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures that are deeply absorbed by the whole company's organization. Product families are clearly distinguished and do not overlap	+ a system is in place to continuously improve the speed and the efficiency of the autonomous units in processing the parts/product families	

Grid area =>	9	10	11	12
Maturity level ‖ V	Technical configurator	Sales configurator	Keeping stocks at optimal levels	Sophisticated and dependable supports for determining available to promise
1	Bills of materials (BOMs) and production sequences (if present) are manually defined by production engineers, eventually copied and modified from similar BOMs/production sequences	Customers, salesmen and technical-sales employees do not have any structured support in choosing all the specific characteristics of the product and in controlling their compatibility	We do not have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) and maintain working capital (finished products, modules, components, parts and raw materials) at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stock or that are in production are available to promise
2	For some product families, BOMs and/or production sequences are automatically generated for a lot of possible variants of the product family, starting from the provided product specifications	Customers, salesmen and the technical-sales employees have structured support (but do not have any SW support) in choosing all the specific characteristics of the product and in controlling their compatibility	We have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an acceptable level	If we look for a certain quantity of a given finished product, we know how much of it is available to promise in our stocks and how much is available to promise in production, but in the latter case, we are not really dependable regarding when they will be available in the warehouse. If the product is not yet launched into production, we apply some fixed lead times for the promise that are common for several products
3	For almost all product families, BOMs and/or production sequences are automatically generated for most of the possible variants of the product family, starting from the provided product specifications	Customers and/or salesmen and/or technical sales employees use SW that supports them in choosing the main characteristics of the products and in controlling their compatibility (at least for the most important product families)	We have a production planning and control system that can assure a very good service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at a very low level	We know exactly how much of each product is available to promise, both in our stocks and in production and, in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	BOMs and production sequences (if needed) are automatically generated for almost all possible variants, starting from the provided product specifications	Customers and/or salesmen use SW that supports them in choosing all the characteristics of the products and in controlling their compatibility (for all or almost all of the product families)	We have a production planning and control system that can assure us an optimal service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an optimal level	We are able to tell exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of company in the given grid area

Company is currently in between the maturity levels in the given grid area

Company is in transition from one maturity level to another in the given grid area

SKIPPED Grid area skipped because workshop participants considered this area irrelevant to their company

Figure 15. MC maturity level for the hydraulic power units product family – Metalmeccanica SPA

Grid area =>	1	2	3	4	5	6
Maturity level II V	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Product modularization	Grouping of parts into families through a similarity-based classification system	Product space organized in clearly distinguished product families
1	Never done	No attention is paid to parts proliferation by the organization, design/production engineers and purchasing staff	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	No modularization at all	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	No product families (modular and/or scaled) exist
2	There is a systematic procedure to eliminate parts no longer needed and this procedure is done periodically for some part families	No guidelines and no SW support exist, but design/production engineers and purchasing staff pay attention to parts proliferation	It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	In some of our product families, the products have been thought about in such a way that each product function is performed by a specific chunk and does not need to interact with other chunks	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through use of production and design engineers' experience; no structured classification system exists	A portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. But, the clustering is not guided by design procedures
3	There is a systematic procedure to eliminate parts no longer needed, and this procedure is done periodically for all part families	Guidelines for design/production engineers and purchasing staff exist and are applied; no SW support	+ there are rules and SW support to limit the introduction of new production sequences	We thought all of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through a structured manual classification system	A considerable portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures. The distinction between product families is good, but can still be considerably improved
4		Guidelines for design/production engineers and purchasing staff exist and are applied very rigorously; SW support exists	+ we make production sequences that differentiate products as late as possible	Our modules may have a longer life than single product families (product platforms exist)	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through an automatic (SW) classification system	The whole product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures that are deeply absorbed by the whole company's organization. Product families are clearly distinguished and do not overlap

Grid area =>	7	8	9	10	11	12
Maturity level II V	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	Low and continuously reduced set-up times SKIPPED	Technical configurator	Sales configurator	Keeping stocks at optimal levels	Sophisticated and dependable supports for determining available to promise
1	Machines are clustered on the shop floor based on their functional similarity	Set-up times are VERY LONG; no systematic reductions of set-up times are being applied	Bills of materials (BOMs) and production sequences (if present) are manually defined by production engineers, eventually copied and modified from similar BOMs/production sequences	Customers, salesmen and technical-sales employees do not have any structured support in choosing all the specific characteristics of the product and in controlling their compatibility	We do not have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) and maintain working capital (finished products, modules, components, parts and raw materials) at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stock or that are in production are available to promise
2	Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated	Set-up times are NEITHER LONG NOR SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) or by application of special tools dedicated to part families and/or product families	For some product families, BOMs and/or production sequences are automatically generated for a lot of possible variants of the product family, starting from the provided product specifications	Customers, salesmen and the technical-sales employees have structured support (but do not have any SW support) in choosing all the specific characteristics of the product and in controlling their compatibility	We have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an acceptable level	If we look for a certain quantity of a given finished product, we know how much of it is available to promise in our stocks and how much is available to promise in production, but in the latter case, we are not really dependable regarding when they will be available in the warehouse. If the product is not yet launched into production, we apply some fixed lead times for the promise that are common for several products
3	+ the positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through autonomous production units	Set-up times are VERY SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up etc.) and by application of special tools dedicated to part families and/or product families	For almost all product families, BOMs and/or production sequences are automatically generated for most of the possible variants of the product family, starting from the provided product specifications	Customers and/or salesmen and/or technical sales employees use SW that supports them in choosing the main characteristics of the products and in controlling their compatibility (at least for the most important product families)	We have a production planning and control system that can assure a very good service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at a very low level	We know exactly how much of each product is available to promise, both in our stocks and in production and, in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	+ a system is in place to continuously improve the speed and the efficiency of the autonomous units in processing the parts/product families		BOMs and production sequences (if needed) are automatically generated for almost all possible variants, starting from the provided product specifications	Customers and/or salesmen use SW that supports them in choosing all the characteristics of the products and in controlling their compatibility (for all or almost all of the product families)	We have a production planning and control system that can assure us an optimal service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an optimal level	We are able to tell exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of company in the given grid area

Company is currently in between the maturity levels in the given grid area

Company is in transition from one maturity level to another in the given grid area

SKIPPED *Grid area skipped because workshop participants considered this area irrelevant to their company*

Figure 16. MC maturity level for the flexible hoses product family – Metalmeccanica SPA

Grid area =>	1	2	3	4	5	6	7	8	9	10	11	12
Maturity level ⇓	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Product modularization	Grouping of parts into families through a similarity-based classification system	Product space organized in clearly distinguished product families	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	Low and continuously reduced set-up times SKIPPED	Technical configurator	Sales configurator	Keeping stocks at optimal levels	Sophisticated and dependable supports for determining available to promise
1	Never done	No attention is paid to parts proliferation by the organization, design/production engineers and purchasing staff	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	No modularization at all	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	No product families (modular and/or scaled) exist	Machines are clustered on the shop floor based on their functional similarity	Set-up times are VERY LONG; no systematic reductions of set-up times are being applied	Bills of materials (BOMs) and production sequences (if present) are manually defined by production engineers, eventually copied and modified from similar BOMs/production sequences	Customers, salesmen and technical-sales employees do not have any structured support in choosing all the specific characteristics of the product and in controlling their compatibility	We do not have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) and maintain working capital (finished products, modules, components, parts and raw materials) at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stock or that are in production are available to promise
2	There is a systematic procedure to eliminate parts no longer needed and this procedure is done periodically for some part families	No guidelines and no SW support exist, but design/production engineers and purchasing staff pay attention to parts proliferation	It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	In some of our product families, the products have been thought about in such a way that each product function is performed by a specific chunk and does not need to interact with other chunks	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through use of production and design engineers' experience; no structured classification system exists	A portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. But, the clustering is not guided by design procedures	Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated	Set-up times are NEITHER LONG NOR SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) or by application of special tools dedicated to part families and/or product families	For some product families, BOMs and/or production sequences are automatically generated for a lot of possible variants of the product family, starting from the provided product specifications	Customers, salesmen and the technical-sales employees have structured support (but do not have any SW support) in choosing all the specific characteristics of the product and in controlling their compatibility	We have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an acceptable level	If we look for a certain quantity of a given finished product, we know how much of it is available to promise in our stocks and how much is available to promise in production, but in the latter case, we are not really dependable regarding when they will be available in the warehouse. If the product is not yet launched into production, we apply some fixed lead times for the promise that are common for several products
3	There is a systematic procedure to eliminate parts no longer needed, and this procedure is done periodically for all part families	Guidelines for design/production engineers and purchasing staff exist and are applied; no SW support	+ there are rules and SW support to limit the introduction of new production sequences	We thought all of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through a structured manual classification system	A considerable portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures. The distinction between product families is good, but can still be considerably improved	+ the positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through autonomous production units	Set-up times are VERY SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up etc.) and by application of special tools dedicated to part families and/or product families	For almost all product families, BOMs and/or production sequences are automatically generated for most of the possible variants of the product family, starting from the provided product specifications	Customers and/or salesmen and/or technical sales employees use SW that supports them in choosing the main characteristics of the products and in controlling their compatibility (at least for the most important product families)	We have a production planning and control system that can assure a very good service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at a very low level	We know exactly how much of each product is available to promise, both in our stocks and in production and, in the latter case, we are very dependable regarding when the product will be available in the warehouse
4		Guidelines for design/production engineers and purchasing staff exist and are applied very rigorously; SW support exists	+ we make production sequences that differentiate products as late as possible	Our modules may have a longer life than single product families (product platforms exist)	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through an automatic (SW) classification system	The whole product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures that are deeply absorbed by the whole company's organization. Product families are clearly distinguished and do not overlap	+ a system is in place to continuously improve the speed and the efficiency of the autonomous units in processing the parts/product families		BOMs and production sequences (if needed) are automatically generated for almost all possible variants, starting from the provided product specifications	Customers and/or salesmen use SW that supports them in choosing all the characteristics of the products and in controlling their compatibility (for all or almost all of the product families)	We have a production planning and control system that can assure us an optimal service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an optimal level	We are able to tell exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of company in the given grid area

Company is currently in between the maturity levels in the given grid area

Company is in transition from one maturity level to another in the given grid area

SKIPPED *Grid area skipped because workshop participants considered this area irrelevant to their company*

Figure 17. MC maturity level for the assembly lines product family – Metalmeccanica SPA

6) **Generating new ideas for advancement in the grid area**

After the MC maturity levels for the three product families were determined (Figure 15, Figure 16 and Figure 17), the workshop proceeded towards the next step in the evaluation procedure: generation of new ideas for advancement in the grid areas. To generate new ideas, the company staff was asked to propose new solutions that would, in their opinion, improve the company's position in the specific grid area. The ideas generation was moderated by the research team in order to help company staff deliver and record the ideas in a clear way.

Company staff had different inspirations and interests and spent different amounts of time for each grid area. In some of the grid areas, ideas for improvement were generated, and in other grid areas, no ideas were generated. Altogether, six ideas were generated for eleven available grid areas (Table 21), since the workshop participants skipped one grid area (8 Low and continuously reduced set-up times).

Table 21. Overview of the ideas generated for advancement during step 6 of the MC maturity grid evaluation procedure – Metalmeccanica SPA

Step	Grid area	Generated idea
1	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Analyze the historical use of parts
2	2 Standardization of parts: Day-by-day limitation of new parts introduction	Create a system that will offer the main option and alternative options for some parts in the design process
3	3 Standardization of production sequences	Define different throughput times for different product types
4	11 Keeping stocks at optimal levels	Planning supplier by using realistic delivery times and not the required supply lead-times
5	12 Sophisticated and dependable supports for determining available to promise	-
6	4 Product modularization	Study modularization of the hydraulic power units family of products
7	6 Product space organized in clearly distinguished product families	-
8	5 Grouping of parts into families through a similarity-based classification system	-
9	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	-

10	8 Low and continuously reduced set-up times	SKIPPED
11	9 Technical configurator	-
12	10 Sales configurator	Define a commercial dialogue to guide the choices of sizing of the hydraulic power units

It must be emphasized that all ideas were generated only for the hydraulic power units (HPUs) product family. For the two other families (flexible hoses and assembly lines), no ideas were generated.

On the one hand, an explanation for the lack of idea generation for the flexible hoses product family may lie in the fact that this part of the product assortment is closely related to the HPU products. Flexible hoses are mainly used as sub-assemblies incorporated into the more complex HPUs. So, we can assume that the ideas generated were generated for these two families together. From the MC maturity levels in Figure 15 and Figure 16, we can see that there are only slight differences between the maturity levels of these two product families. On the other hand, it is interesting that no ideas were generated for the assembly lines product family. The lack of generated ideas can be attributed to one or a combination of the following:

- Most of the design process of the assembly lines is done by the Original Producer SPA[12] and not by the examined company. Metalmeccanica SPA takes orders from the customers and tailors the pre-made Original Producer SPA designs for their needs. This could have a negative effect on the employees, who might presume that someone else is doing the complete job of production organization for them. In reality, that is not the case.
- In four of the grid areas, this product family is better positioned than the other two product families. In the rest of the grid areas (except one), it is on the same level as the other two product families. This could be the reason that the responsible engineers do not feel a need to further advance MC maturity level of this product family.
- Human factors can also be the reason for lack of ideas generation. If engineers and managers lack the experience or simply lack the ability to generate ideas, ideas will not be generated even if they are obvious to the rest of the company staff. If this is the case, the company should address this problem in order to enable idea generation in the future. Regarding this point, some MC experts suggested that

[12] 'Original Producer SPA' is a fake name used to keep confidentiality of the company data

> ‘strong persons’ in the group could drive the discussion in their preferred direction and thus influence the outcome of the workshop. Nevertheless, this did not happen, neither in Metalmeccanica SPA nor in Soft Automation SPA. Some of the reasons this did not occur may lie in the nature of the grid itself and in the implementation procedure, which does not allow one specific participant to ‘drive the conversation’ on one specific point; the fact that different participants are usually responsible for different product families, which reduces the possibility of impacting the area of another manager/engineer; and the fact that both workshops were marked by a clear feeling of open discussion and no manipulation was experienced.

Whatever the reasons, the fact is, the company has a product family that was marked as being on maturity level 1 or 2 in four grid areas, but the staff did not generate any ideas for advancing its MC level. This is an issue for the company management to deal with in the future. The outcome of the analysis could be that the process is rigid in terms of advancement, and is dictated in large amount by the original product manufacturer. If this is the case, there is really no advancement possible. An analysis is recommended by the research team in order to gain a clear understanding of whether the lack of ideas can be attributed to the nature of the product assortment or to the human factor or to something else. Only in this way will further advancement in the grid areas for the assembly lines product family be possible in the future.

7) **Prioritizing the generated ideas**

The step for prioritizing the ideas followed after the ideas for advancement were generated. In this step, the company staff, together with the research team, discussed the priority of every generated idea, the impacts on company performance caused by the idea, the efforts needed to implement the idea, and, in the end, the interconnections with other grid areas and ideas, if any exist.

The levels for marking the characteristics of the ideas are of a qualitative nature, namely: low, medium, high and very high. Combinations of the listed levels, such as medium-low or medium-high were also allowed if the participants found it necessary to use these inter-levels in order to describe certain characteristics of the model.

In the rest of the summary of step 7 of the evaluation procedure, the ideas generated for Metalmeccanica SPA are presented and discussed.

***Idea 1** – Analyze the historical use of parts*

Grid area: 1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed

Determined maturity level of the company in the grid area: 1–2 (in transition to level 2)

Idea explanation: The main purpose of the idea is to analyze the historical use of parts in production. In this way, the company can create a base to make standardization of the parts and move closer to the creating a procedure for periodic rationalization of the parts.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other dimensions
Medium	High	Low	No

***Idea 2** – Create a system that will offer the main option and alternative options for some parts in the design process*

Grid area: 2 Standardization of parts: Day-by-day limitation of new parts introduction

Determined maturity level of the company in the grid area: 3 (in transition to level 4)

Idea explanation: The main goal of the idea is to try to make adjustments in the process of product design so that only a restricted number of parts are offered to the design engineers. The options should be offered in such a way that the preferred option is offered first and, if that preferred option is not acceptable to the designer and the customer, then alternatives would be offered. This proposal would help design engineers focus on the preferred parts, reducing the scope of parts used in production.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other dimensions
Medium	High	High	4 Product modularization and 1 Standardization

***Idea 3** – Define different throughput times for different product types*

Grid area: 3 Standardization of production sequences

Determined maturity level of the company in the grid area: 1–2 (in transition to level 2)

Idea explanation: The main goal of this idea is to analyze whether in reality different product families have different cycle times. If cycle times differ, then product families should be treated differently. For the moment, the company is using estimated times for all of the product families, which is probably not suitable for all products.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other dimensions
Low	Medium-Low	Low	No

***Idea 4** – Study modularization of the hydraulic power units family of products*
Grid area: 4 Product modularization
Determined maturity level of the company in the grid area: 1
Idea explanation: The main goal of this idea is to conduct a study in order to modularize the complete hydraulic power unit.
Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other dimensions
Medium-Low	High	High	10 Sales configurator (commercial dialogue) and 1 and 2 Standardization (partially)

***Idea 5** – Define a commercial dialogue to guide the choices for sizing the hydraulic power units*
Grid area: 10 Sales configurator
Determined maturity level of the company in the grid area: 1–2
Idea explanation: The main goal of this idea is to create a procedure that will guide the sales process. At first, the procedure would be paper based and then it would be translated into an Excel file. It is important to emphasize that the goal of this step is not to create a sales dialogue to be put into the product configurator but just to take the company to the next level of guiding the sales process.
Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other dimensions
Medium	High	Medium	some interdependencies with 1 and 2 Standardization (grid areas 1 and 2)

Idea 6 *– Planning supplier by using realistic delivery times and not required supply lead-times*

Grid area: 11 Keeping stocks at optimal levels

Determined maturity level of the company in the grid area: 2

Idea explanation: The main goal of this idea is to use realistic delivery times in planning and production. At the moment, the company is having problems using the desired planning time for scheduling purposes, which is leading to high pressure on the design department and on production, which have to cope with unrealistic deadlines.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other dimensions
Very High	High	Medium-Low	No

8) **Generating the implementation plan**

After each idea was rated, the workshop participants conducted an overview of all of the ideas in order to create a possible sequence for the realization of the ideas with the ratings of the priorities in mind.

In Table 22, the generated MC implementation plan is provided. In the implementation plan, ideas are listed by priorities for their realization. Notably, the workshop group concluded that there is a need to put Idea 1 and Idea 2 together in the realization sequence because they present proposals that are strongly related and that should be realized at the same time.

Table 22. Generated MC implementation plan – Metalmeccanica SPA

Realiz. order	Idea	Priority	Impact	Effort	Interdependence
1	Planning supplier by using realistic delivery times and not the required supply lead-times (grid area 11)	VH	H	ML	No
2	A combined idea (ideas 1 and 2): • Analyze the historical use of parts (idea 1) • Create a system that will offer a main option and alternative options for some parts in the design process (idea 2) (grid areas 1 and 2)	M	H	H	4 Product Modularization

3	Define a commercial dialogue to guide the choices for sizing of the hydraulic power units (grid area 10)	M	H	M	Some, with Standardization (grid areas 1 and 2)
4	Study modularization for the hydraulic power units family of products (grid area 4)	ML	H	H	10 Sales configurator (commercial dialogue) and 1 and 2 Standardization (partially)
5	Define different throughput times for different product types (grid area 3)	L	ML	L	No
Legend: L – Low; ML – Medium-Low; M – Medium; H – High; VH – Very High					

9) **Determining the overall suitability and significance of the MC maturity grid**

- **The overall usefulness of the MC maturity grid**
  The MC maturity grid was rated as useful from the company's point of view.
- **Some new insights the MC maturity grid has provided to the company staff**
  New insights the MC maturity grid has provided to the company staff are that there can be improvements without having to cope with a huge project. Insights that proved to be important are the interdependencies of the grid areas, which led to generating feasible ideas.
- **Thoughts about the future applicability of the MC maturity grid in their company**
  The company asked for collaboration on future implementation of the generated ideas, which was by itself proof that the MC maturity grid works and from now on can be considered valid.

Concluding the analysis of the results, it is clear that the observational evaluation conducted in a manufacturing SME—Metalmeccanica SPA—resulted in a clear plan for implementation activities as the main expected outcome of the MC maturity grid application. Besides validation of the MC maturity grid in practice, a number of new insights and proposals for advancement of the MC maturity grid were obtained. These insights and proposals have been gathered and applied in the refinement of the MC maturity grid (section 2.5).

2.4.4 MC maturity grid observational evaluation in Soft Automation SPA

2.4.4.1 Soft Automation SPA company overview

The Soft Automation SPA[13] company was founded in 1978. The company designs and manufactures systems for automation, control, monitoring and manufacturing execution systems (MESs) for various industries. Besides offering software solutions, the company provides its customers with support and maintenance of their customers' production systems as well as support for further evolution in the life cycle of the client company.

The three main industry sectors in which the company has competencies and clients are the food industry, the power industry and other companies from the manufacturing sector. Soft Automation SPA currently has 35 employees, so it is regarded as a small enterprise.

The reason the company agreed to MC maturity grid evaluation is that in recent years it has been experiencing an increase in the diversity of the services it has to provide to its industry customers. In other words, the variety of products and services is increasing. Besides the increase in the variety of its product assortment, the scope of the production system the company must handle when implementing its solutions is increasing with the development of information technologies.

Company management has come to the conclusion that it is necessary to do something in terms of higher utilization of the existing product design solutions and better addressing the solution space the company offers its customers, in order to make the process of product development and services providing easier for the company.

On the one hand, similar to Metalmeccanica SPA, Soft Automation SPA did not know what to expect from the application of the MC maturity grid. On the other hand, company management was convinced that something had to be done about the product assortment and management of it. The company management's conclusion was that increasing product and service variety could be a big problem in the future and could lead to shortages in its capacity to meet customer demands, as well as increasing the difficulty of providing services to the existing clients.

Notably, prior to the MC maturity grid evaluation, some of the company management was aware of the mass customization concept, but only knew the principles and had a basic understanding of the concept.

In addition to the production of software for production automation, Soft Automation SPA does revamping of existing production systems that are out of date in comparison to the global trends in their industry. Companies that are revamped in such a way extend the life cycle of their existing equipment, for which the problem is mostly the outdated control parts of machines. In this way, the lifecycle of the whole production system is substantially extended.

[13] 'Soft Automation SPA' is a fake name used to keep confidentiality of the company data

Software production involves the development of software for the automation of individual machines as well as for machine integration and coordinated management at higher levels. The role of developed software in production is very diverse and ranges from machine management, machine control, machine monitoring, changing parameters such as temperature and pressure, etc. Therefore, the software connects the machine (or machines) to the information system of the company.

On the one hand, Soft Automation SPA's problem is that it has difficulty presenting the scope of what it really does and is capable of doing to a potential client. On the other hand, the company maintains a constant relationship with regular clients with its very broad competencies.

Another very big problem for Soft Automation SPA is that it is difficult for them to find and train new salespeople for products that would attract new customers. The company finds it difficult to train new people to sell, so the most experienced engineers must spend their time selling the products. This presents a problem for the company because it is the most expensive time of the company staff, and it could be used for delivering products and services that bring profits. To address this issue, company management came up with the idea of structuring knowledge of the enterprise so that, in the future, training young professionals would last for several months instead of the current time of a few years. These trained salespeople would free up the time of the most experienced engineers. Of course, these employees would have significantly lower wages than the experienced engineers.

Different software solutions in the enterprise are produced in different ways. Thus, in the energy sector, software solutions are based on the software components that are supplied by the Soft-Supplier company[14] through partnership. In the food industry and in other industries, the company designs software solutions used for automation. But, whether it is Soft-Supplier's solutions or their own software, there are basically software components that can be seen as parts or modules that together provide future software solutions.

An important component of the company's offerings is the possibility of reconfiguring their clients' production systems. The company possesses broad competencies in terms of automating and revamping production systems; however, as has already been noted, in recent years the company has been facing a huge expansion in the scope of work that needs to be covered. The scope of the production system that has to be brought under control by the company's software solutions is rapidly increasing. This is due to the development of information technology, which, more and more, is connecting the different levels of the organization and different locations of the company. In addition, the company is often asked to perform tasks such as sorting a database for

[14] 'Soft-Supplier company' is a fake name used to keep confidentiality of the company data

the client company, which it often agrees to perform for its permanent clients, but these additional tasks consume additional time.

It is expected that the level of products and services customization that the company offers is high because they are provided to production companies that represent unique cases. In this sense, the company management's idea of increasing the reusability of ready-made products and improving the model for delivering its services is correct. As one of the managers said: 'It is necessary to industrialize knowledge of the company'.

The company's problem is that when a client comes in need of a service, a team of 4 to 5 senior people must be established in order to answer the client's questions. These are people that are already assigned to a number of other projects. The reason for establishing a team is that the knowledge is possessed by the senior people and has not been formalized or gathered by the company. For example, company engineers possess vast experience and knowledge not only of new machines but also of 20-, 30- or 40-year-old machines used in production.

Soft Automation SPA is also working with engineering-procurement-construction (EPC) companies. This is the case when a factory is built from the ground up for the final buyer. These projects are important for Soft Automation SPA because such projects have their own rules and are much more structured than others projects the company deals with. Notably, once the work on a new factory is completed, the new factory owner usually becomes a customer of Soft Automation SPA.

2.4.4.2 Workshop group for MC maturity grid evaluation - Soft Automation SPA

The group for the MC maturity grid evaluation was composed of six persons. Four of them were company representatives evaluating the grid and two were university members.

The company representatives for Soft Automation SPA were:

- A technical director
- A manager of department for research and development
- A manager of department for industrial automation
- A manager of department for development of automation in the energy plants industry

Notably, mainly electronics and mechanical engineers composed the company group, of which, some possess a degree in engineering management.

The company representatives were selected based on the need for the MC maturity grid evaluation. The group was made up of engineers who are in charge of the management, production, development and commercial activities of the company. This group is responsible for changes in product and process design and organizational aspects of the business. In practice, this is the group that would be responsible for implementing the changes identified through the MC maturity grid application.

The research team that did the evaluation was composed of two persons:

- A PhD candidate (Nikola Suzić) and
- A mentoring professor (Cipriano Forza).

2.4.4.3 Overview of the process of the MC maturity grid evaluation in Soft Automation SPA

Notably, after the first two short introduction steps of the evaluation procedure were completed, the next one-and-a-half hours was spent on understanding the product assortment of Soft Automation SPA. On the one hand, this clearly shows that the company has a problem presenting what it provides to the market. On the other hand, it should be noted that this is a company where the majority of employees have university degrees and are highly trained and specialized in the operations they perform. It should also be noted that the company did not use a product catalogue, brochure or any other written document to present its product assortment to the research team.

After the introduction and a long discussion about the company's product assortment, every grid area was discussed. An overview of the sequence of evaluation of every grid area is provided in Table 23.

Table 23. Overview of the MC maturity grid evaluation sequence in Soft Automation SPA

Temporal sequence	Number of evaluation procedure step (Figure 13)	Evaluation step/Grid area
1	1	Introduction to use of the MC maturity grid
2	2	Explanation of the procedure for MC maturity grid evaluation
3	-	Clarification of the Soft Automation SPA product assortment
4	3, 4, 5 and 6	6 Product space organized in clearly distinguished product families
5	3, 4, 5 and 6	10 Sales configurator
6	3, 4, 5 and 6	9 Technical configurator
7	3, 4, 5 and 6	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed
8	3, 4, 5 and 6	2 Standardization of parts: Day-by-day limitation of new parts introduction
9	3, 4, 5 and 6	3 Standardization of production sequences
10	3, 4, 5 and 6	4 Product modularization
11	SKIPPED	5 Grouping of parts into families through a similarity-based classification system
12	SKIPPED	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families
13	SKIPPED	8 Low and continuously reduced set-up times

14	SKIPPED	11 Keeping stocks at optimal levels
15	SKIPPED	12 Sophisticated and dependable supports for determining available to promise
16	7	Prioritizing the generated ideas
17	8	Generating the implementation plan
18	9	Determining the overall suitability and significance of the MC maturity grid

Table 23 shows that the evaluation of grid areas once again did not strictly follow the order in the MC maturity grid. The sequence was changed ad hoc, as in the case of Metalmeccanica SPA, because the company staff made comments leading to the conclusion that there should be a change in the sequence of evaluation and the discussion should be led in different way.

2.4.4.4 Results of the observational evaluation – Soft Automation SPA

Interestingly, as opposed to Metalmeccanica SPA, in Soft Automation SPA there was no clear division between the product families in the process of the MC maturity level assessment. As a consequence, only one MC maturity level was derived for the whole company.

In Table 24, grid areas are listed by the amount of time it took for them to be successfully processed by the workshop participants. Table 24 also shows three clusters of grid areas that were created based on the time spent on each of the grid areas.

Table 24. Grid areas listed according to the amount of time it took to process them – Soft Automation SPA

Time slot	Grid area	Total time spent on grid area (min.)	Grid area clusters
1	6 Product space organized in clearly distinguished product families	1:03:00	Grid area cluster 1 – grid areas to which the group gave most attention Total time spent: 2 h Average time per grid area: 1 h
2	10 Sales configurator	57:00	
3	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	54:00	Grid area cluster 2 – grid areas to which the group gave medium attention Total time spent: 54 min Average time per grid area: 13,5 min
4	2 Standardization of parts: Day-by-day limitation of new parts introduction		
5	3 Standardization of production sequences		
6	4 Product modularization		

			NOTE: The four grid areas from this cluster were not separated during the analysis but were processed together. So, the time provided is the total for all four grid areas
7	9 Technical configurator	5:00	Grid area cluster 3 – grid areas to which the group gave least attention Total time spent: 12 min Average time per grid area: 2 min *NOTE: The last five grid areas of cluster 3 were skipped because they were marked as irrelevant for the company*
8	5 Grouping of parts into families through a similarity-based classification system	3:00	
9	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	1:00	
10	8 Low and continuously reduced set-up times	1:00	
11	11 Keeping stocks at optimal levels	1:00	
12	12 Sophisticated and dependable supports for determining available to promise	1:00	

Table 24 lists all of the grid areas based on the total time spent for discussion of each grid area. On the one hand, the amount of time spent on the explanation of every grid area was similar for all of the grid areas, varying from 1 minute to 3 minutes (2 minutes on average). On the other hand, the amount of time that workshop participants spent on each grid area varied drastically, from 1 minute for skipped grid areas (Table 23) up to an hour and three minutes for grid area 6 (Product space organized in clearly distinguished product families). The conclusion for grid areas 5, 7, 8, 11 and 12, which were skipped, was that these grid areas have no real relevance for the company's performance because this company provides services and produces software solutions and there is no real shop floor. In light of the short analysis, the discussions of these grid areas were completed very quickly. However, for the grid areas from cluster 1 (Table 24), participants took their time, dedicating an average of one full hour for processing each of the two grid areas. This clearly signals that these are the grid areas of most importance to the company at this moment.

From the analysis, it can be assumed that organizing the product assortment in clearly distinguished product families (grid area 6) and managing the sales through IT-based product configuration (grid area 10) are the most critical areas that need to be worked on from the viewpoint of the company staff. This assumption is based on the time they spent to process these grid areas, and this is also in line with inability of the company's most senior people to present their product assortment clearly and concisely. Unfortunately, Soft Automation SPA did not prioritize the generated ideas (Table 26), which means that it was not possible to compare the time spent discussing each grid area with the priority assigned to the generated ideas, which could have confirmed these assumptions. The other cluster of grid areas that encompass standardization and product modularization were processed together, without a clear distinction between them (grid areas 1, 2, 3 and 4). From the analysis done after the workshop, we can conclude that these are highly connected grid areas that are 'foggy' for the company staff. Thus, for company staff, it was not possible to clearly separate the grid areas in the first meeting.

In the following part of the chapter, the results of each evaluation step from the procedure for MC maturity grid evaluation (Figure 13) are presented.

1) **Introduction to use of the MC maturity grid** – NOTHING TO REPORT

2) **Explanation of the procedure for MC maturity grid evaluation** – NOTHING TO REPORT

*) **Presentation of the company product assortment** – This step is not part of the procedure. In the first case (Metalmeccanica SPA), this step was short and it was done within the two introduction steps. However, in Soft Automation SPA, this step took a considerable amount of time (one hour and thirty minutes). Therefore, this step is reported here just to provide an overview of the evaluation flow that is as complete as possible. Certainly the emergence of this step has to be taken into account for the further refinement of the evaluation/use procedure of the MC maturity grid.

3) **Evaluation of the grid areas**

- **The suitability of the number of the grid areas**
  During the grid evaluation, company staff noted that some grid areas were developed for manufacturing companies. This comment was further confirmed in the evaluation procedure, where five grid areas were skipped. These five grid areas (grid areas 5, 7, 8, 11 and 12) are in fact the ones that address the shop floor of the production system. Thus, skipping them was not surprising for the research team. Therefore, except for some grid areas not being suitable for the company, the issue of the size of the MC maturity grid was not raised. Also, there was no proposal from the company staff to add new grid areas.
- **The understandability of the grid area titles**
  No objections were made to the titles of any of 12 grid areas. The titles of the grid areas were well understood and well received from the company staff.

Notably, the explanation provided by the moderators (research team) while company staff was reading the grid area titles helped in understanding the meaning of the grid area titles.

4) **Evaluation of the maturity levels**

As in the case of the first MC maturity grid evaluation, company staff encountered some difficulties understanding the maturity levels of the grid areas when reading on their own. Thus, in order to facilitate understanding, the research team focused explanations on the differences between the maturity levels. Again, this moderation effort substantially helped the company staff in the use of the grid. Therefore, the conclusion from the first testing that the MC maturity grid should be used under the guidance of a moderator and with several interactions with the company staff was confirmed.

This part of evaluation dealt with:

- **Suitability of the maturity levels for every grid area**

  In general, the maturity levels of the grid areas were found suitable for use. However, in some cases (1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed, 6 Product space organized in clearly distinguished product families, and 10 Sales configurator), company staff identified positions in between the levels as the right ones. These in-between levels will be discussed later. Further, in five cases (grid areas 5, 7, 8, 11 and 12), maturity levels were not discussed in detail because the company staff concluded that these grid areas had no impact on their production performance.

- **Clarity of the maturity levels descriptions**

  In general, the maturity levels descriptions were clear to the company staff, requiring only a short introduction to the grid areas. Notably, for grid areas 5, 7, 8, 11 and 12, the clarity of the maturity levels descriptions was not discussed in detail because the company staff concluded that these grid areas had no impact on their production performance.

5) **Determining the maturity level of the company in the grid area**

The assessed MC maturity level of the company determined during the MC maturity grid evaluation is presented in this part of the evaluation overview.

Although it was obvious to the research team that there was a possibility to separate the product assortment and to do an assessment of the MC maturity level for each of the separate parts, this was not done. The research team did not push this idea, since there was no clear will from the company staff to make this separation at the beginning of the evaluation procedure. Thus, one MC maturity level was determined for the whole of Soft Automation SPA (Figure 18).

Grid area =>	1	2	3	4	5	6	7	8	9	10	11	12
Maturity level ⇓	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Product modularization	Grouping of parts into families through a similarity-based classification system SKIPPED	Product space organized in clearly distinguished product families	Organizing machines/assembly stations on the shop floor in order to maximize the efficiency of processing part/product families SKIPPED	Low and continuously reduced set-up times SKIPPED	Technical configurator	Sales configurator	Keeping stocks at optimal levels SKIPPED	Sophisticated and dependable supports for determining available to promise SKIPPED
1	Never done	No attention is paid to parts proliferation by the organization, design/production engineers and purchasing staff	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	No modularization at all	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	No product families (modular and/or scaled) exist	Machines are clustered on the shop floor based on their functional similarity	Set-up times are VERY LONG; no systematic reductions of set-up times are being applied	Bills of materials (BOMs) and production sequences (if present) are manually defined by production engineers, eventually copied and modified from similar BOMs/production sequences	Customers, salesmen and technical-sales employees do not have any structured support in choosing all the specific characteristics of the product and in controlling their compatibility	We do not have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) and maintain working capital (finished products, modules, components, parts and raw materials) at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stock or that are in production are available to promise
2	There is a systematic procedure to eliminate parts no longer needed and this procedure is done periodically for some part families	No guidelines and no SW support exist, but design/production engineers and purchasing staff pay attention to parts proliferation	It is easy to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	In some of our product families, the products have been thought about in such a way that each product function is performed by a specific chunk and does not need to interact with other chunks	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through use of production and design engineers' experience; no structured classification system exists	A portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. But, the clustering is not guided by design procedures	Machines and assembly stations are able to process different parts/products with similar efficiency and are clustered based on the part/product families to which they are dedicated	Set-up times are NEITHER LONG NOR SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) or by application of special tools dedicated to part families and/or product families	For some product families, BOMs and/or production sequences are automatically generated for a lot of possible variants of the product family, starting from the provided product specifications	Customers, salesmen and the technical-sales employees have structured support (but do not have any SW support) in choosing all the specific characteristics of the product and in controlling their compatibility	We have a production planning and control system that can assure an acceptable service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an acceptable level	If we look for a certain quantity of a given finished product, we know how much of it is available to promise in our stocks and how much is available to promise in production, but in the latter case, we are not really dependable regarding when they will be available in the warehouse. If the product is not yet launched into production, we apply some fixed lead times for the promise that are common for several products
3	There is a systematic procedure to eliminate parts no longer needed, and this procedure is done periodically for all part families	Guidelines for design/production engineers and purchasing staff exist and are applied; no SW support	+ there are rules and SW support to limit the introduction of new production sequences	We thought all of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through a structured manual classification system	A considerable portion of the product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures. The distinction between product families is good, but can still be considerably improved	+ the positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through autonomous production units	Set-up times are VERY SHORT; reductions of process set-up times are achieved by continuous analysis of and changes made in the technology used (use of machines with low set-up times, fasteners, positioning aids, standardized tools, etc.) and organization (standardization of set-up procedure, using offline set-up etc.) and by application of special tools dedicated to part families and/or product families	For almost all product families, BOMs and/or production sequences are automatically generated for most of the possible variants of the product family, starting from the provided product specifications	Customers and/or salesmen and/or technical sales employees use SW that supports them in choosing the main characteristics of the products and in controlling their compatibility (at least for the most important product families)	We have a production planning and control system that can assure a very good service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at a very low level	We know exactly how much of each product is available to promise, both in our stocks and in production and, in the latter case, we are very dependable regarding when the product will be available in the warehouse
4		Guidelines for design/production engineers and purchasing staff exist and are applied very rigorously; SW support exists	+ we make production sequences that differentiate products as late as possible	Our modules may have a longer life than single product families (product platforms exist)	Parts are grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes); part families are formed through an automatic (SW) classification system	The whole product assortment is composed of products clustered in product families (modular and/or scaled) according to similarities in product functions and product-related production processes. Clustering is guided by design procedures that are deeply absorbed by the whole company's organization. Product families are clearly distinguished and do not overlap	+ a system is in place to continuously improve the speed and the efficiency of the autonomous units in processing the parts/product families		BOMs and production sequences (if needed) are automatically generated for almost all possible variants, starting from the provided product specifications	Customers and/or salesmen use SW that supports them in choosing all the characteristics of the products and in controlling their compatibility (for all or almost all of the product families)	We have a production planning and control system that can assure us an optimal service level at the subsequent stage (production of parts, assembly of final products or product delivery to the customer) while maintaining working capital (finished products, modules, components, parts and raw materials) at an optimal level	We are able to tell exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of company in the given grid area

Company is currently in between the maturity levels in the given grid area

Company is in transition from one maturity level to another in the given grid area

SKIPPED Grid area skipped because workshop participants considered this area irrelevant to their company

Figure 18. MC maturity level for Soft Automation SPA

6) **Generating new ideas for advancement in the grid area**

After MC maturity level for the company was determined (Figure 18), the workshop proceeded to the next step in the evaluation procedure: generation of new ideas for advancement in the grid areas. The company staff was asked to propose new solutions that would improve the company's position in the specific grid area. The research team moderated the ideas generation process in order to help company staff deliver and record ideas in a clear way.

Company staff had different inspirations and interests and spent different amounts of time for each grid area. In some of the grid areas, ideas for improvement were generated, and in other grid areas no ideas were generated. Altogether, three ideas were generated for the seven available grid areas, since five grid areas (5, 7, 8, 11 and 12) were skipped by the workshop participants earlier. An overview of the ideas generated for each grid area is provided in Table 25.

Table 25. Overview of the ideas generated for advancement during step 6 of the MC maturity grid evaluation procedure – Soft Automation SPA

Step	Grid area	Generated idea
1	6 Product space organized in clearly distinguished product families	Formalize the product families; classify and study the product trends; and analyze the market opportunities for the current products
2	10 Sales configurator	Determine the activities that compose the products/services and list them
3	9 Technical configurator	-
4	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	-
5	2 Standardization of parts: Day-by-day limitation of new parts introduction	-
6	3 Standardization of production sequences	-
7	4 Product modularization	Modularize the high-level software and manufacturing execution systems (MES)
8	5 Grouping of parts into families through a similarity-based classification system	SKIPPED
9	7 Organizing machines/assembly stations on the shop floor in order to the maximize the speed and efficiency of processing part/product families	SKIPPED

10	8 Low and continuously reduced set-up times	SKIPPED
11	11 Keeping stocks at optimal levels	SKIPPED
12	12 Sophisticated and dependable supports for determining available to promise	SKIPPED

Ideas were generated for the whole product assortment, with a developed plan for the first implementation of every idea. Thus, the situation for product families that had no generated ideas, as in the case of Metalmeccanica SPA, was not repeated here.

7) **Prioritizing the generated ideas**

After ideas for advancements were generated, the step for prioritizing the ideas was performed. In this step, company staff, together with the research team, discussed the priority of every generated idea, the impacts on company performance caused by the idea, the efforts needed to implement the idea and, in the end, the interconnections with other grid areas and ideas, if any exist.

The levels for marking the characteristics of the ideas are qualitative in nature, namely: low, medium, high and very high. Combinations of the listed levels, such as medium-low or medium-high, were also allowed if the participants found it necessary to use these inter-levels to describe certain characteristics of the model. In the rest of the summary of step 7 of the evaluation procedure, the ideas generated for Soft Automation SPA are presented and discussed.

Idea 1 *– Formalize the product families; classify and study the product trends; and analyze the market opportunities for the current products*

Grid area: 6 Product space organized in clearly distinguished product families

Determined maturity level of the company in grid area: 2–3

Idea explanation: The main purpose of this idea is to formalize the product families. The product families are, to some extent, clear to company staff, but they need to be explicitly formalized. The process should be continued with identification of product segments, customers, markets, etc. It is expected that clear identification of the market segments and customers already served will create opportunities to approach similar customers with similar service/product offerings.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other grid areas
NOT SPECIFIED	- Low - in the short term - High - in the long term	Low	Positive effect on grid area 10 Sales configurator

Idea 2 *– Determine the activities that compose the products/services and list them*

Grid area: 10 Sales configurator

Determined maturity level of the company in grid area: 1–2

Idea explanation: The main goal of this idea is to list all of the activities and components Soft Automation SPA is delivering to the customer. With all of the activities specified, the customer can perceive the value the company is delivering. Although the activities should be specified, pricing for a large group of activities should leave enough flexibility for the company to specify the correct price of each activity later. The idea is to start the analysis, listing and pricing of activities with the energy plant projects. This analysis would lead to the development of a sales configurator in Excel or a similar basic configurator for energy plant projects. This basic sales configurator would contain activities and component prices that are somewhat detailed (e.g. controller – as a component type), but not too specific (e.g. Controller P126 – as a specific controller, with specific characteristics and a predetermined price). The final configuration of the activities and components would be finalized later in the sales process when the sale is more certain and further work on a detailed offer and project configuration is meaningful. In this way, the creation of a proposal is sped up and the complexity of the proposal and price of making it is lowered.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other grid areas
NOT SPECIFIED	Medium – in the short term	Low – for energy plants High – for the whole product assortment	Positive interactions with 6 Product space organized in clearly distinguished product families

***Idea 3** – Modularize the high-level software and manufacturing execution systems (MES)*

Grid area: 4 Product modularization

Determined maturity level of the company in grid area: 2

Idea explanation: The idea should be implemented starting from the micro-objects provided by the Soft-Supplier company for the energy sector. Soft-Supplier has already standardized these micro-objects, but the goal is to build macro objects using the modularity principle. Thus, macro objects should be standardized and rules for building them defined upfront. After success with the energy plants sector, the same idea would be implemented for the proprietary software.

Part of this idea is also to investigate modularizing the MES the company provides. The company also has both proprietary and non-proprietary software in the MES segment. Thus, when a project is run for a client, the question is which MES or parts of the MES to use. Although this idea was not expressed as clearly as for the energy plants, company staff agreed that there is a need to research this topic further.

Idea characteristics

Priority	Impact on company performance	Effort to implement	Interdependencies with other grid areas
NOT SPECIFIED	High – when implemented	Medium	Positive interactions with 10 Sales configurator

8) **Generating the implementation plan**

After each idea was rated, the workshop participants conducted an overview all of the ideas in order to create a possible sequence for the realization of the ideas with the priorities that were given and their ratings in mind.

Notably, priorities were not specified during the idea generation phase. In the phase of generating the implementation plan, company staff did not appoint priorities to the ideas once again. Further, neither company staff nor the research team found any constraints for the parallel or independent realization of the three ideas. Thus, in the final implementation plan, generated ideas are listed, but they are not in any particular sequence (Table 26).

Table 26. Generated MC implementation plan – Soft Automation SPA

Realiz. order	Idea	Priority	Impact	Effort	Interdependence
-	Formalize the product families; classify and study the product trends; and analyze the market opportunities for the current products (grid area 6)	N/S	L – in the short term H – in the long term	L	Positive effect on grid area 10 Sales configurator
-	Determine the activities that compose products/services and list them (grid area 10)	N/S	M – in the short term	L – for energy plants H – for the whole product assortment	Positive interactions with 6 Product space organized in clearly distinguished product families
-	Modularize the high-level software and manufacturing execution systems (MES) (grid area 4)	N/S	H – when imple-mented	M	Positive interactions with 10 Sales configurator
Legend: *L – Low; M – Medium; H – High; VH – Very High; N/S – Not specified*					

9) **Determining the overall suitability and significance of the MC maturity grid**

- **The overall usefulness of the MC maturity grid**
  The MC maturity grid was rated as useful from the company's point of view.
- **Some new insights the MC maturity grid has provided to the company staff**
  Even though Soft Automation SPA is a company of only 35 people, the assessment done through use of the MC maturity grid raised some similarities between the various parts of the product assortment with regard to product modularization that were not known before the MC maturity grid application. The manager of the energy plants sector commented on this: 'We didn't know that the situation of the different families was similar. The analysis helped'.
- **Thoughts about the future applicability of the MC maturity grid in their company**
  The company suggested that a second meeting would probably be needed in order to go deeper into project elaboration.

Concluding the analysis of the results, it can be seen that the observational evaluation conducted in the second testing company, a service SME (Soft Automation SPA), again resulted in a clear plan of implementation activities as the main expected outcome of the MC maturity grid application. As in the first company (Metalmeccanica SPA), besides validation of the MC maturity grid in practice, a number of new insights and proposals for advancement of the MC maturity grid were obtained. These insights and proposals have been gathered and applied in the refinement of the MC maturity grid (section 2.5).

2.5 Refinements of the MC maturity grid based on the observational evaluation

During the MC maturity grid evaluation in two SMEs, some of the observations and suggestions were recorded regarding the original outlook (Figure 13) and functionality of the grid. These observations/suggestions and the eventual changes made based on them are summarized in this chapter. The potential changes are divided into the topics they cover, namely:

- Adequacy of grid areas
- Appropriateness of the maturity levels
- Appearance of the MC maturity grid
- Changing the sequence of the grid areas in the MC maturity grid
- Changing the grid area titles and cell text
- Adding new grid areas
- Other important notes from the MC maturity grid evaluation
- Proposals for grid refinement generated through interviews with managers, consultants and academics

Finally, the sub-chapter provides the refined MC maturity grid and the conclusions of the MC maturity grid observational evaluation.

2.5.1 Adequacy of grid areas

During the MC maturity grid evaluations there were no standard times for processing a single grid area. This was due to the fact that the company staff in both cases focused on those grid areas that were more meaningful to them and to the company's current needs.

During the evaluation some grid areas lacked the attention of the company staff. For Metalmeccanica SPA, this was grid area 8 (Low and continuously reduced set-up times). From the company's point of view, this grid area does not have any relevance for the production processes because there is currently no real set-up time on their machines. The research team agreed that this grid area has no significance for the moment, so the discussion of this grid area was closed. For Soft Automation SPA, five grid areas were skipped, but this was not surprising because the company provides services and produces software, which means that some grid areas are simply not applicable and can be skipped for the moment. In both SMEs, other grid areas received substantial attention from the company staff, confirming the adequacy of the grid areas of the MC maturity grid.

Therefore, from experience in two SMEs, it can be concluded that skipping some grid areas can be expected in MC maturity grid application in SMEs. Skipping some grid areas does not decrease the validity of the MC maturity grid. On the contrary, the possibility of skipping some grid areas and still continuing with the MC maturity grid application implies that the grid is capable of coping with a wide range of different SMEs and company as-is situations.

It is important to say that it could be that skipped grid areas are not important to the company at the moment, but as the company develops its MC capabilities and advances in the different grid areas, the skipped grid areas could become more significant for the company and improvements in these grid areas could be done then.

2.5.2 Appropriateness of the maturity levels

The functionality of the MC maturity grid is to a large extent based on the ability of a company to locate itself in the maturity levels of each grid area. This was carefully observed during the MC maturity grid evaluations.

After a specific grid area was explained, the company staff was asked to determine the maturity level of their company at this moment in the given grid area.

During this part of evaluation, some new insights were obtained:

1. *In-between level positions* – In some cases, as in the case of grid area 1 (Standardization of parts: Periodic rationalization to eliminate parts no longer needed) in Metalmeccanica SPA, the company staff could not place the company in any of the existing maturity levels. Instead, they placed their company between maturity levels 1 and 2. This in-between level positioning occurred in both of the observational evaluations, showing their validity, and they will be used in future applications of the MC maturity grid. Regarding this decision to use in-between level positions, one could argue that in-between level positions could be inserted into the grid as separate maturity levels. After analyzing this possibility, a couple of strong reasons were found against this idea: firstly, adding new maturity levels in the grid would substantially raise the complexity of the grid—or at least the perceived complexity of the grid; secondly, with new levels inserted, it would take more time for practitioners to read the grid; and thirdly, it is not certain that in future applications of the grid there would not be cases where a company could not find itself in the newly added maturity levels. Thus, the idea of augmenting the MC maturity grid with these in-between levels as new maturity levels was discarded.
2. *Transition position* – In some cases recorded in Metalmeccanica SPA, after identifying the maturity level in a grid area, company staff stated that they were already actively moving towards the next maturity level in the specific grid area.

During the evaluation, this was depicted with an arrow to mark that the company is in a transition process (Figure 15 and Figure 16). Thus, a transition position was made valid since the evaluation showed that it is meaningful for company staff and for precision of the assessment.

3. *Separate MC maturity level assessment for every product family* – In some cases there was a need to mark more than one level of one grid area. In fact, the more the product families are distinguished or the production processes are kept apart in the company, the greater the need to mark more than one maturity level in some grid areas. In this case, different product families should be treated as different companies altogether. This does not present a disadvantage. On the contrary, separating product families provides every product family a chance to advance in maturity levels, not being treated within some overall MC maturity level of the company, but as higher or lower in some of the grid areas.

2.5.3 Appearance of the MC maturity grid

There were no proposals for changes to the MC maturity grid's appearance during the evaluation, neither from the companies nor from the research team.

2.5.4 Changing the sequence of the grid areas in the MC maturity grid

A new sequence for the grid areas in the MC maturity grid was made based on the ability of company staff to focus on similar and interconnected grid areas. This principle was applied before the grid evaluation, but new connections and similarities were noticed during the evaluation and should be applied.

During the MC maturity grid evaluation in Metalmeccanica SPA, it was noticed that the effects of the grid would be better if grid area 5 (Grouping of parts into families through a similarity-based classification system) was placed immediately after grid area 3 (Standardization of production sequences), and if the grid area 6 (Product space organized in clearly distinguished product families) was placed before grid area 4 (Product modularization). This was apparently closer to practitioners' mindset. The grid evaluation in Soft Automation SPA did not provide new insights for changing the grid area sequence. A new sequence for the grid areas as well as the reasons for position changes are given in Table 27.

Table 27. New grid area sequence for the MC maturity grid based on the evaluation results

Position	Grid area	Reason for position change
1	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	NO CHANGE
2	2 Standardization of parts: Day-by-day limitation of new parts introduction	NO CHANGE
3	3 Standardization of production sequences	NO CHANGE
4	5 Grouping of parts into families through a similarity-based classification system	Putting this grid area closer to the Standardization grid areas. With focus of the workshop group already on standardization, it is easier to focus on grouping parts into families.
5	6 Product space organized in clearly distinguished product families	Moved because of the term 'product families', which needs to be 'absorbed' by the company staff in this grid area. Afterwards, it is easier to explain and discuss the Product modularization grid area.
6	4 Product modularization	Moved after grid areas 5 and 6 as a consequence of the position change of these two grid areas.
7	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	NO CHANGE
8	8 Low and continuously reduced set-up times	NO CHANGE
9	9 Technical configurator	NO CHANGE
10	10 Sales configurator	NO CHANGE
11	11 Keeping stocks at optimal levels	NO CHANGE
12	12 Sophisticated and dependable supports for determining available to promise	NO CHANGE

2.5.5 Changing the grid area titles and cell text

During the observational evaluations of the MC maturity grid it was noticed that some of the text or some of the words in the grid area titles and/or cell text describing the maturity levels could be improved. These following changes have been made:

- *Mention of 'modular and/or scaled' product families was removed* – In grid area 6 (Product space organized in clearly distinguished product families), it turned out that these notions are only misleading the company staff.
- *Cell text that contains a large amount of text descriptions were significantly shortened* – A large amount of text makes explanations more difficult. If a broader explanation is needed, the company staff can be offered a full description by the moderator(s). The purpose of the cell text is to explain the concept, while the concept should be clear to the person using the MC maturity grid (research team in the two testing cases), who can further explain the details of the grid area and every maturity level.

2.5.6 Adding new grid areas

In Soft Automation SPA, there was no proposal for adding new grid areas to the MC maturity grid. However, in Metalmeccanica SPA, discussion with the company staff led to opening the question of quality control that was not covered in the grid.

The MC maturity grid is basically for dealing with product variety and customization. On the one hand, the main purpose of the grid lies in upgrading these fields. On the other hand, all of the grid areas deal with product quality to certain extent, either by directly raising the product quality with advancement in grid area maturity levels or by raising product quality through upgrading product-related processes.

For the moment, introducing a quality control grid area is not seen as a need in the MC maturity grid. But, during future applications of the grid, this issue should be carefully tracked and, if it is frequently raised by companies, it should be addressed in MC maturity grid changes. The positive side is that the MC maturity grid has proven itself to be highly flexible, thus, adding new grid areas does not present a problem.

2.5.7 Other important notes from the MC maturity grid evaluation

In this part of the chapter, important notes related to the procedure for MC maturity grid use are provided.

- The notion of standardization (both parts and production sequences) is not understood in the same way by practitioners and there is a need to explain the concept in more detail when addressing the company staff and applying the MC maturity grid.
- Grid areas addressing standardization (especially grid areas 1 and 2) should be viewed together in order to generate ideas on a higher level and in order that the company staff more clearly understands the problems of standardization.

- The atmosphere of the group workshop is 'alive' all the time, and the company staff participated actively in the discussion all the time. This is a sign that the MC maturity grid is working and that working with grid areas is a good match for group workshop application.
- The MC maturity grid does not indicate a specific area to work on. Obviously, the grid implicitly suggests that the weakest area should be considered for possible improvements. However, the choice to focus on a given area is deliberately left to the initiative of company users. In this way they signaled initiatives that they feel they can and will do. During the evaluation of the MC maturity grid it was noted that the ideas generated were generated in the grid areas in which company staff marked their position as low (maturity level 1 or 2). Five of six ideas in Metalmeccanica SPA and two of three ideas for Soft Automation SPA were generated in such grid areas. This can be explained as a consequence of company staff feeling that there is a need for improvement in a particular grid area. In addition, there is a perception of the research team that for some of the grid areas, company staff had a sense that there was something to be done before the grid evaluation was conducted, but the opportunity and resources to generate ideas were not easily available to them, which is not surprising for SMEs. Further, with the application of a structured approach (i.e. MC maturity grid), feasible ideas were generated in a relatively short period of time. This demonstrates that the balance in the grid areas is important for the company and that there is a tendency for problems to appear in grid areas that have lower maturity levels rather than in the grid areas that have a higher maturity level. Thus, it is natural that in these grid areas the ideas for solving these problems will also appear.
- The MC maturity grid does not state any specific sequence for the implementation of enablers. However, the grid makes company users aware of the main dimensions a company very likely first or later, has to work on to become a mass customizer. This property of the grid was appreciated in both companies where grid was tested.
- The MC maturity grid evaluation has shown that managing variety and customization is a very broad issue with a lot of aspects to consider. However, the proposed grid has shown that it is very good in at locating specific problems in product variety management and in generating ideas for solving them. Therefore, by using the MC maturity grid, a company can identify some possible steps towards greater mass customization capability.

- Discussing specific topics (grid areas) one at a time helped users analyze the system properly and generate ideas.
- Ideas generated were not far from the knowledge of the company staff, but SME engineers and managers have limited 'time to think' and generate ideas on their own in their everyday work and without a guiding process.
- In the process of MC maturity grid evaluation, company staff got the chance to discover meaningful ideas that can be applied.
- Analysis and prioritization of the generated ideas proved an important step for the company staff, which is witnessed in a quote from one of the Metalmeccanica SPA managers after application of the grid: 'Now we know what we have to work on'.
- Metalmeccanica SPA lacks capital, human and time resources. After the whole procedure was completed, one of the engineers stated: 'We have no resources to make everything at the same time, so we have to start from one, then the second, the third... In this way, we can afford it, otherwise no.' This statement confirms the choice of SMEs as a context for MC maturity grid development.
- Commenting on the generated implementation plan, one of the design engineers (HBU product family) stated: 'Among many things, we know on which we have to work on, from which side and which point we have to start working'. This statement confirms that application of the MC maturity grid in Metalmeccanica SPA was instantly perceived as a benefit to the company's further development in terms of moving towards MC.

2.5.8 Proposals for grid refinement generated through interviews with managers, consultants and academics

Besides the proposals for grid refinement generated during the observational evaluation in two SMEs, the decision was made to implement some other proposals that were generated in interviews with managers, consultants and academics. Some of the proposals were generated before and some after the observational evaluation.

- Making the grid symmetrical – During the interviews, the symmetry of the grid was mentioned. One of the proposals was to try to build all the maturity levels based on the same structure. Although this idea was tempting, in the end it could not be achieved. However, the notion of symmetry was picked up. Thus, the decision was made to generate one more level for grid areas 1 (Standardization of parts: Periodic rationalization to eliminate parts no longer needed) and 8 (Low and continuously reduced set-up times). For grid area 1, a maturity level was generated between levels 1 and 2, moving the second and third level down one place; and for grid area 8, maturity level 1 was generated, moving all other levels one place down.

- The use of emphasized (uppercase) words – This change was adopted because it proved to be good practice in grid areas 3 and 7 during the observational evaluation.
- The suggestion for decreasing the amount of text was adopted – This improvement led to better understandability of cell text, and also enabled a slight increase in the font size used in the MC maturity grid, which in the end enhanced the readability of the text.
- Reorganizing the text into small paragraphs where possible – The text was organized into small paragraphs in order to enhance the understandability and speed up the reading of the text. Large chunks of text that were used in the second version of the grid were split where possible.
- The notion of 'scaled product families' was removed from grid area 5 (Product space organized in clearly distinguished product families) – The notion of 'scaled product families' was found to be confusing for some of the interviewed experts. Thus, it was removed because the observational evaluation also showed that this notion does not add any significant benefit to grid area 5.

2.5.9 Refined MC maturity grid

Based on the suggestions of the company staff, the insights the research team gained during the observational evaluation and another round of interviews with managers, consultants and academics, proposals for changes to the MC maturity grid were gathered, evaluated and introduced. Thus, a refined MC maturity grid was created (Figure 19).

Grid area => / Maturity level ⇓	1	2	3	4	5	6	7	8	9	10	11	12
	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Grouping of parts into part families through a similarity-based classification system	Product space organized in clearly distinguished product families	Product modularization	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	Low and continuously reduced set-up times	Technical configurator	Sales configurator	Keeping stocks at optimal levels	Sophisticated and dependable supports for determining available to promise
1	Never done	NO attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff and (2) the organization	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	Products are not clustered in product families	No modularization at all	Machines are clustered on the shop floor based on their functional similarity	We do not have a clear view of set-up times because we have never considered them	BOMs and PSs (if present) are manually defined possibly by modifying similar BOMs/PSs *(BOM - bill of materials PS - production sequence)*	Customers, salesmen and the technical-sales employees (CSTS) do not have any structured support to choose the specific characteristics of the product and to control their compatibility	We do not have a production planning and control system that assures an acceptable service level at the subsequent stage *(production of parts, assembly of final products or delivering product to the customer)* and maintains working capital *(finished products, modules, components, parts and raw materials)* at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stocks or are in production are available to promise
2	We standardized the parts and we eliminated parts no longer needed *BUT* this was an isolated initiative	Attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff (2a) NO parts standardization guidelines (2b) NO SW supports for part standardization	(1) It is easy for design/production engineers to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	(1) Parts ARE grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes), (2) The criteria used are NOT FORMALIZED and coincide with the production and design engineers' experience	(1) A PORTION of the product assortment is composed of products clustered in product families according to similarities in product functions and product-related production processes (2) But the way the clustering is obtained is NOT GUIDED by design procedures	(1) In SOME of our product families, all of the products have been thought about such that each product function is performed by a specific chunk (module) and is not performed through interaction with more chunks	(1) Machines and assembly stations are able to process different parts/products (within a family) with similar efficiency *AND* (2) Machines and assembly stations are clustered based on the part/product families to which they are dedicated	(1) Set-up times are VERY LONG *AND* (2) No systematic reductions of set-up times are being applied	for A LOT of possible product variants of SOME product families BOM and/or PS are automatically generated	CSTS have a structured support (without SW) to choose ... and control ...	We have a production planning and control system that assures an acceptable service level at the subsequent stage (...) and maintains working capital (...) at an acceptable level	We know how much of each product is available to promise both in our stocks and in production but in the latter case, we are not really dependable regarding when they will be available in the warehouse. if the product is not yet launched into production, we apply some fixed lead times that are common for several products for the promise
3	(1) There is a systematic procedure to eliminate parts no longer needed *AND* (2) This procedure is periodically done on SOME part families	(1, 2a) Part standardization guidelines for design/production engineers and purchasing staff exist and are SOMEHOW applied, (2b) NO SW support	(1) .... *AND* (2) There are rules and SW support to limit the introduction of new production sequences	(1) .... *AND* (2) Part families are formed through a FORMALIZED and structured MANUAL classification system	(1) A CONSIDERABLE PORTION of the product assortment is ... *idem* ... (2) The way the clustering is obtained is GUIDED by design procedures (3) The distinction between product families is good, but can still be improved considerably	(1) We designed ALL of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	(1) .... *AND* (2) .... *AND* (3) The positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through them	(1) Set-up times are NEITHER LONG NOR SHORT *AND* (2) Reductions of process set-up times are achieved by continuous analysis of and changes made in: used technology (use of machines with low set-up times, fasteners, positioning aids, standardized tools,etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) OR by application of special tools (dedicated to part families and/or product families)	for MOST possible product variants of ALMOST ALL product families BOM and/or PS are automatically generated	C or S or TS use software to choose the MAIN characteristics of the products and to control their compatibility (at least for the MOST IMPORTANT product families)	We have a production planning and control system that assures a very good service level at the subsequent stage (...) and maintains working capital (...) at a very low level	We know how much of each product is available to promise both on our stocks and in production and, even in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	(1) .... *AND* (2) This procedure is periodically done on ALL part families	(1, 2a) Guidelines for design/production engineers and purchasing staff exist and are applied very RIGOROUSLY, (2b) SW support exists	(1) .... *AND* (2) .... *AND* (3) We make production sequences that differentiate products as late as possible	(1) .... *AND* (2) Part families are formed through an AUTOMATIC (SW) classification system	(1) THE WHOLE product assortment is ... *idem* ... (2) ...*idem* ... and these design procedures are DEEPLY ABSORBED by the whole organization (3) Product families are CLEARLY DISTINGUISHED and do not overlap each other	(1) .... *AND* (2) Our modules may have a longer life than single product families (product platforms exist)	(1) .... *AND* (2) .... *AND* (3) .... *AND* (4) A system is in place to continuously improve the speed and efficiency of the autonomous units in processing parts/product families	(1) Set-up times are VERY SHORT *AND* (2) Reductions of process set-up times are achieved by ...*idem* ... AND by application of special tools ...*idem* ...	for ALMOST ALL possible product variants of ALL product families BOM and/or PS are automatically generated	C and/or S use a software to choose ALL of the characteristics of the products and to control their compatibility (for ALL or ALMOST ALL of the product families)	We have a production planning and control system that assures an optimal service level at the subsequent stage (...) and maintains working capital (...) at an optimal level	We know exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Figure 19. Refined MC maturity grid (Note: '(1)..............' should be read as 'text previously marked with "(1)" in this grid area is repeated here')

2.6 Long-term observational evaluation of the MC maturity grid

After the observational evaluation in two SMEs and the generation of implementation plans, the time came for companies to put the plans into action. Since the implementation of every initiative takes time, the SMEs were left to do the implementation. In order not to generate bias in the research results, communication with both companies was restricted and no additional support was offered from the research team.

After almost three years, the two SMEs were approached again in order to find out:

- If the generated implementation plan was followed by the companies
- If advancements in the company's MC status were made in almost three years
- If the developed MC maturity grid is capable of recording the changes that occurred in the MC status of the companies

For the purpose of long-term observational evaluation, three tools were used:

- A set of questions to guide the discussion about the effects of the MC maturity grid application in the company
- The implementation plan generated for the SME during the observational evaluation
- A refined MC maturity grid (Figure 19) to identify possible advancements in the maturity levels generated over the period of almost three years

The first tool, the set of questions, is reported in presentation of the long-term observational evaluation; the second tool, implementation plans generated for two SMEs during the observational evaluation, are provided previously in sections 2.4.3.4 and 2.4.4.4; and the third tool, refined MC maturity grid, is provided in Figure 19 (section 2.5.9). So, these three tools are not presented here in order to avoid redundancies.

2.6.1 MC maturity grid long-term observational evaluation in Metalmeccanica SPA

A set of questions was used for the first part of the long-term observational evaluation (Table 28). These questions were used in order to reconstruct the story of the application of the generated implementation plan, as well as the overall impact the MC maturity grid had on Metalmeccanica SPA.

Table 28. Results of the long-term observational evaluation in Metalmeccanica SPA

Question	Summarized answers
How and why did the company agree to participate in the MC maturity grid assessment?	- The main reason for participation was that there was an understanding that the company had grown in previous years and there was a need to address system complexity and product variety issues
How did you choose the participants?	- The participants were chosen among the senior management staff of the company. Thus, they have technical knowledge of the products and processes as well as the power to determine and implement changes
From today's perspective, did the assessment using the MC maturity grid provide a good overview of the status of variety/customization management in your company?	- Yes - The assessment made workshop participants aware of the company's status regarding the MC
Was the assessment efficient?	- Yes. A lot of issues were covered in a relatively short period of time
Did the grid help in breaking barriers, building consensus and taking responsibility?	- Yes - The group workshop organized around the grid stimulated discussion among the company staff and generated ideas.
What were the main issues pointed out by the analysis?	- The main issue pointed out by analysis was that there is a need to take a holistic approach to advancements in various functions of the company - The company recognized that incremental steps are essential for balanced development because resources are scarce
Can you remember the generated implementation plan?	- Participants could not remember the exact generated implementation plan, but during the discussion, all of the ideas that were generated were restated and expanded. This means that the original plan was probably augmented in the course of time and merged with other company activities and managers' and engineers' thought processes
Was the grid used after the first assessment? If yes, how frequently, for how long?	- No. The company saw no need to reuse the grid
If it was used, for what purposes was it used?	N/A
Was the generated plan implemented?	- Most of the generated plan was implemented - The SME is still working on some of the ideas generated, since these ideas need more time to be implemented

Did you use external support to implement the plan?	- No. The company has one young manager with a master degree in engineering management, with considerable suitable knowledge. The presence of this manager on the team was most likely the reason that external support was not sought for realizing the implementation plan
Do you think your experience with the MC maturity grid changed something in the presentation of your product assortment, in the way you see the company, in the organization of the production, and so on?	- Yes - The way regular customers are served has changed in a way that they are guided to order the same products or products that are very similar to the ones they have bought before. This approach substantially reduces the time spent to produce an offer and effectively reduces the product variety actually required

Company staff stressed that one of the main contributions from the use of the MC maturity grid was an opportunity to have a guided inter-functional discussion on the MC status of the company. They also stressed that the grid represents a very good way to assess the current situation of the company in various areas with regard to product variety and customization.

An overview of the realized ideas was performed in the discussion (Table 29). In the end, two generated ideas were completely implemented, while three other ideas are in the process of realization because they require longer realization time or resources simply have to be dedicated to them.

Table 29. Realization of the ideas generated in the implementation plan in Metalmeccanica SPA

Real. order	Idea	Priority	Impact	Effort	Interdependence	Realized
1	Planning supplier by using realistic delivery times and not the required supply lead-times (grid area 11)	VH	H	ML	No	IN PROCESS
2	A combined idea (ideas 1 and 2): • Analyze the historical use of parts (idea 1) • Create a system that will offer a main option and alternative options for some parts in the design process (idea 2) (grid areas 1 and 2)	M	H	H	6 Product modularization	YES

3	Define a commercial dialogue to guide the choices for sizing of the hydraulic power units (grid area 10)	M	H	M	Some, with Standardization (grid areas 1 and 2)	IN PROCESS
4	Study modularization for the hydraulic power units family of products (grid area 6)	ML	H	H	10 Sales configurator (commercial dialogue) and 1 and 2 Standardization (partially)	IN PROCESS
5	Define different throughput times for different product types (grid area 3)	L	ML	L	No	YES
Legend: L – Low; ML – Medium-Low; M – Medium; H – High; VH – Very High; N/S – Not specified						

In the final step of the long-term observational evaluation, the company staff was asked to make a current assessment of the company as-is situation. Their assessment shows that for the hydraulic power units family, Metalmeccanica SPA made advancements in five of six grid areas where ideas were generated: grid areas 1, 2, 6, 10 and 11 (Figure 23). In addition to this, significant advancements were also made for the product families for flexible hoses and assembly lines (Figure 21 and Figure 22).

Grid area => / Maturity level ‖ V	1	2	3	4	5	6	7	8	9	10	11	12
	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Grouping of parts into part families through a similarity-based classification system	Product space organized in clearly distinguished product families	Product modularization	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	Low and continuously reduced set-up times SKIPPED	Technical configurator	Sales configurator	Keeping stocks at optimal levels	Sophisticated and dependable supports for determining available to promise
1	Never done	NO attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff and (2) the organization	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	Products are not clustered in product families	No modularization at all	Machines are clustered on the shop floor based on their functional similarity	We do not have a clear view of set-up times because we have never considered them	BOMs and PSs (if present) are manually defined possibly by modifying similar BOMs/PSs *(BOM - bill of materials PS - production sequence)*	Customers, salesmen and the technical-sales employees (CSTS) do not have any structured support to choose the specific characteristics of the product and to control their compatibility	We do not have a production planning and control system that assures an acceptable service level at the subsequent stage *(production of parts, assembly of final products or delivering product to the customer)* and maintains working capital *(finished products, modules, components, parts and raw materials)* at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stocks or are in production are available to promise
2	We standardized the parts and we eliminated parts no longer needed *BUT* this was an isolated initiative	Attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff (2a) NO parts standardization guidelines (2b) NO SW supports for part standardization	(1) It is easy for design/production engineers to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	(1) Parts ARE grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes), (2) The criteria used are NOT FORMALIZED and coincide with the production and design engineers' experience	(1) A PORTION of the product assortment is composed of products clustered in product families according to similarities in product functions and product-related production processes (2) But the way the clustering is obtained is NOT GUIDED by design procedures	(1) In SOME of our product families, all of the products have been thought about such that each product function is performed by a specific chunk (module) and is not performed through interaction with more chunks	(1) Machines and assembly stations are able to process different parts/products (within a family) with similar efficiency *AND* (2) Machines and assembly stations are clustered based on the part/product families to which they are dedicated	(1) Set-up times are VERY LONG *AND* (2) No systematic reductions of set-up times are being applied	for A LOT of possible product variants of SOME product families BOM and/or PS are automatically generated	CSTS have a structured support (without SW) to choose ... and control ...	We have a production planning and control system that assures an acceptable service level at the subsequent stage (...) and maintains working capital (...) at an acceptable level	We know how much of each product is available to promise both in our stocks and in production but in the latter case, we are not really dependable regarding when they will be available in the warehouse. if the product is not yet launched into production, we apply some fixed lead times that are common for several products for the promise
3	(1) There is a systematic procedure to eliminate parts no longer needed *AND* (2) This procedure is periodically done on SOME part families	(1, 2a) Part standardization guidelines for design/production engineers and purchasing staff exist and are SOMEHOW applied, (2b) NO SW support	(1) .... *AND* (2) There are rules and SW support to limit the introduction of new production sequences	(1) .... *AND* (2) Part families are formed through a FORMALIZED and structured MANUAL classification system	(1) A CONSIDERABLE PORTION of the product assortment is ... *idem* ... (2) The way the clustering is obtained is GUIDED by design procedures (3) The distinction between product families is good, but can still be improved considerably	(1) We designed ALL of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	(1) .... *AND* (2) .... *AND* (3) The positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through them	(1) Set-up times are NEITHER LONG NOR SHORT *AND* (2) Reductions of process set-up times are achieved by continuous analysis of and changes made in: used technology (use of machines with low set-up times, fasteners, positioning aids, standardized tools,etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) OR by application of special tools (dedicated to part families and/or product families)	for MOST possible product variants of ALMOST ALL product families BOM and/or PS are automatically generated	C or S or TS use software to choose the MAIN characteristics of the products and to control their compatibility (at least for the MOST IMPORTANT product families)	We have a production planning and control system that assures a very good service level at the subsequent stage (...) and maintains working capital (...) at a very low level	We know how much of each product is available to promise both in our stocks and in production and, even in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	(1) .... *AND* (2) This procedure is periodically done on ALL part families	(1, 2a) Guidelines for design/production engineers and purchasing staff exist and are applied very RIGOROUSLY, (2b) SW support exists	(1) .... *AND* (2) .... *AND* (3) We make production sequences that differentiate products as late as possible	(1) .... *AND* (2) Part families are formed through an AUTOMATIC (SW) classification system	(1) THE WHOLE product assortment is ... *idem* ... (2) ...*idem* ... and these design procedures are DEEPLY ABSORBED by the whole organization (3) Product families are CLEARLY DISTINGUISHED and do not overlap each other	(1) .... *AND* (2) Our modules may have a longer life than single product families (product platforms exist)	(1) .... *AND* (2) .... *AND* (3) .... *AND* (4) A system is in place to continuously improve the speed and efficiency of the autonomous units in processing parts/product families	(1) Set-up times are VERY SHORT *AND* (2) Reductions of process set-up times are achieved by ...*idem* ... AND by application of special tools ...*idem* ...	for ALMOST ALL possible product variants of ALL product families BOM and/or PS are automatically generated	C and/or S use a software to choose ALL of the characteristics of the products and to control their compatibility (for ALL or ALMOST ALL of the product families)	We have a production planning and control system that assures an optimal service level at the subsequent stage (...) and maintains working capital (...) at an optimal level	We know exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of the company in the given grid area

Company is currently in between the maturity levels in a given grid area

Company is still in transition from one maturity level to another in the given grid area

SKIPPED *Grid area skipped because workshop participants considered this area irrelevant to their company*

Grid area where advancement has been recorded

Advanced maturity level

Maturity level of the company in the first assessment

Company is now in transition from one maturity level to another in the given grid area

Figure 20. Long-term evaluation of the MC maturity level for the hydraulic power units product family – Metalmeccanica SPA

Grid area => / Maturity level ‖ V	1	2	3	4	5	6
	Standardization of parts: periodical rationalization to eliminate parts no more needed	Standardization of parts: day by day limitation of new parts introduction	Standardization of production sequences	Grouping of parts into part families trough similarity-based classification system	Product space organized in clearly distinguished product families	Product modularization
1	never done	NO attention is payed to parts proliferation by: (1) design/production engineers and purchasing staff and (2) the organization	no attention payed by the organization and by the individual design and production engineers to production sequence proliferation	parts are not grouped in families using similarity-based classification criteria (shape and size and materials, and therefore production processes)	product are not clustered in product families	no modularization at all
2	we made a standardization of parts and we eliminated parts no more needed *BUT* this was an isolated initiative	attention to parts proliferation is payed by: (1) design/production engineers and purchasing staff (2a) NO parts standardization guidelines (2b) NO SW supports for parts standardization	(1) it is easy for design/production engineers to reuse the same sequences (because production sequence database is well organized and because production sequences are grouped in classes)	(1) parts ARE grouped in families using similarity-based classification criteria (shape and size and materials, and therefore production processes), (2) the criteria used are NOT FORMALISED and coincide with the production and design engineers experience	(1) A PORTION of product assortment is composed of products clustered in product families according to similarities in product functions and product-related production processes. (2) But the way to obtain the clusterization is NOT NORMED by design procedures	(1) in SOME of our product families we have all the products have been thought in such a way that each product function is performed by a specific chunk (module) and it is not performed through the interaction of more chunks
3	(1) there is a systematical procedure to eliminate parts no more needed *AND* (2) this procedure is periodically done on SOME of part families	(1, 2a) part standardization guidelines for design/production engineers and purchasing staff exist and are SOMEHOW applied, (2b) NO SW support	(1) .... *AND* (2) there are rules and SW support to limit the introduction of new production sequences	(1) .... *AND* (2) part families are formed trough FORMALISED and structured MANUAL classification system	(1) A CONSIDERABLE PORTION of product assortment is ... *idem*... (2) The way to obtain the clusterization is NORMED by design procedures . (3) The distinction between product families is good, but can still considerably be improved.	(1) we designed ALL our families in a modular way: we have families of modules (each function is performed by only one module) with standardized interfaces
4	(1) .... *AND* (2) this procedure is periodically done on ALL of part families	(1, 2a) guidelines for design/production engineers and purchasing staff exist and are applied very RIGOROUSLY, (2b) SW support exists	(1) .... *AND* (2) .... *AND* (3) we make production sequences that differentiate products as late as possible	(1) .... *AND* (2) part families are formed trough AUTOMATIC (SW) classification system	(1) THE WHOLE product assortment is ... *idem*... (2) ...*idem*... and these design procedures are DEEPLY ABSORBED by the whole organization. (3) Product families are CLEARLY DISTINGUISHED and do not overlap each other.	(1) .... *AND* (2) our modules may have a longer life that single product families (product platforms exist)

Grid area => / Maturity level ‖ V	7	8	9	10	11	12
	Organizing machines/assembly stations in shop-floor in order to maximize speed and efficiency in processing part/product families	SKIPPED Low and continuously reduced set up times	Technical configurator	Sales configurator	Keeping stocks on optimal levels	Sophisticated and dependable supports for determining available to promise
1	machines are clustered in the shop-floor based on their function similarity	we do not have a clear view of set-up times because we never considered them	BOM and PS (if present) are manually defined possibly by modifying similar BOM/PS BOM - bill of materials PS - production sequence	customers, salesmen and the technical-sales employees (CSTS) do not have any structured support to choose the specific characteristics of the product and to control their compatibility	we do not have production planning and control system that assures us acceptable service level at the following stage *(production of parts, assembly of final products or delivering product to the customer)* and keeps working capital *(finished products, modules, components, parts and raw materials)* at an acceptable level	it is difficult for us to say weather the products that are available in the finished products stocks or are in production are available to promise or not
2	(1) machines and assembly stations are able to process different parts/products (within a family) with similar efficiency *AND* (2) machines and assembly stations are clustered based on the part/product families to which they are dedicated to	(1) set up times are VERY LONG *AND* (2) no systematical reductions of set up times are being applied	for A LOT of possible product variants of SOME product families BOM and/or PS are automatically generated	CSTS have a structured support (without SW) to choose ... and control ...	we have production planning and control system that assures us acceptable service level at the following stage (...) and keeps working capital (...) at an acceptable level	we know how much of each product is available to promise in both in our stocks and in production but in the later case we are not really dependable on the time they will be available in the warehouse. If the product is not yet launched into production we apply for the promise some fixed lead times that are common for several products.
3	(1) .... *AND* (2) .... *AND* (3) the positioning and organization of the machines/assembly stations minimizes the time that the parts/products spend to pass trough them	(1) set up times are NEITHER LONG OR SHORT *AND* (2) reductions of process set up times are achieved by continuous analysis of and changes made in: used technology *(use of low set up time machines, fasteners, positioning aids, standardization of tools etc.)* and organization *(standardization of set up procedure, using offline set up etc.)* OR by application of special tools *(dedicated to part families and/or product families)*	for MOST possible product variants of ALMOST ALL product families BOM and/or PS are automatically generated	C or S or TS use a software to choose the MAIN characteristics of the products and to control their compatibility (at least for the MOST IMPORTANT product families)	we have production planning and control system that assures us very good service level at the following stage (...) and keeps working capital (...) at a very low level	we know how much of each product is available to promise in both in our stocks and in production and, even in the later case, we are very dependable about the time in which the product will be available in the warehouse
4	+a system in place to continuous improve the speed and the efficiency of the autonomous units in processing parts/product families	(1) set up times are VERY SHORT *AND* (2) reductions of process set up times are achieved by ...*idem*... AND by application of special tools ...*idem*.. .	for ALMOST ALL possible product variants of ALL product families BOM and/or PS are automatically generated	customers and/or salesmen use a software to choose ALL the characteristics of the products and to control their compatibility (for ALL or ALMOST ALL of the product families)	we have production planning and control system that assures us optimal service level at the following stage (...) and keeps working capital (...) at an optimal level	we know exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products in the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of the company in the given grid area

SKIPPED — Grid area skipped because workshop participants considered this area irrelevant to their company

Maturity level of the company in the first assessment

Company is currently in between the maturity levels in a given grid area

Grid area where advancement has been recorded

Company is now in transition from one maturity level to another in the given grid area

Company is still in transition from one maturity level to another in the given grid area

Advanced maturity level

Figure 21. Long-term evaluation of the MC maturity level for the flexible hoses product family – Metalmeccanica SPA

Grid area => / Maturity level	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	2 Standardization of parts: Day-by-day limitation of new parts introduction	3 Standardization of production sequences	4 Grouping of parts into part families through a similarity-based classification system	5 Product space organized in clearly distinguished product families	6 Product modularization
1	Never done	NO attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff and (2) the organization	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	Products are not clustered in product families	No modularization at all
2	We standardized the parts and we eliminated parts no longer needed *BUT* this was an isolated initiative	Attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff (2a) NO parts standardization guidelines (2b) NO SW supports for part standardization	(1) It is easy for design/production engineers to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	(1) Parts ARE grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes), (2) The criteria used are NOT FORMALIZED and coincide with the production and design engineers' experience	(1) A PORTION of the product assortment is composed of products clustered in product families according to similarities in product functions and product-related production processes (2) But the way the clustering is obtained is NOT GUIDED by design procedures	(1) In SOME of our product families, all of the products have been thought about such that each product function is performed by a specific chunk (module) and is not performed through interaction with more chunks
3	(1) There is a systematic procedure to eliminate parts no longer needed *AND* (2) This procedure is periodically done on SOME part families	(1, 2a) Part standardization guidelines for design/production engineers and purchasing staff exist and are SOMEHOW applied, (2b) NO SW support	(1) .... *AND* (2) There are rules and SW support to limit the introduction of new production sequences	(1) .... *AND* (2) Part families are formed through a FORMALIZED and structured MANUAL classification system	(1) A CONSIDERABLE PORTION of the product assortment is ... *idem* ... (2) The way the clustering is obtained is GUIDED by design procedures (3) The distinction between product families is good, but can still be improved considerably	(1) We designed ALL of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces
4	(1) .... *AND* (2) This procedure is periodically done on ALL part families	(1, 2a) Guidelines for design/production engineers and purchasing staff exist and are applied very RIGOROUSLY, (2b) SW support exists	(1) .... *AND* (2) .... *AND* (3) We make production sequences that differentiate products as late as possible	(1) .... *AND* (2) Part families are formed through an AUTOMATIC (SW) classification system	(1) THE WHOLE product assortment is ... *idem* ... (2) ...*idem* ... and these design procedures are DEEPLY ABSORBED by the whole organization (3) Product families are CLEARLY DISTINGUISHED and do not overlap each other	(1) .... *AND* (2) Our modules may have a longer life than single product families (product platforms exist)

Grid area => / Maturity level	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	8 Low and continuously reduced set-up times (SKIPPED)	9 Technical configurator	10 Sales configurator	11 Keeping stocks at optimal levels	12 Sophisticated and dependable supports for determining available to promise
1	Machines are clustered on the shop floor based on their functional similarity	We do not have a clear view of set-up times because we have never considered them	BOMs and PSs (if present) are manually defined possibly by modifying similar BOMs/PSs *(BOM - bill of materials PS - production sequence)*	Customers, salesmen and the technical-sales employees (CSTS) do not have any structured support to choose the specific characteristics of the product and to control their compatibility	We do not have a production planning and control system that assures an acceptable service level at the subsequent stage *(production of parts, assembly of final products or delivering product to the customer)* and maintains working capital *(finished products, modules, components, parts and raw materials)* at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stocks or are in production are available to promise
2	(1) Machines and assembly stations are able to process different parts/products (within a family) with similar efficiency *AND* (2) Machines and assembly stations are clustered based on the part/product families to which they are dedicated	(1) Set-up times are VERY LONG *AND* (2) No systematic reductions of set-up times are being applied	for A LOT of possible product variants of SOME product families BOM and/or PS are automatically generated	CSTS have a structured support (without SW) to choose ... and control ...	We have a production planning and control system that assures an acceptable service level at the subsequent stage (...) and maintains working capital (...) at an acceptable level	We know how much of each product is available to promise both in our stocks and in production but in the latter case, we are not really dependable regarding when they will be available in the warehouse. if the product is not yet launched into production, we apply some fixed lead times that are common for several products for the promise
3	(1) .... *AND* (2) .... *AND* (3) The positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through them	(1) Set-up times are NEITHER LONG NOR SHORT *AND* (2) Reductions of process set-up times are achieved by continuous analysis of and changes made in: used technology (use of machines with low set-up times, fasteners, positioning aids, standardized tools,etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) OR by application of special tools (dedicated to part families and/or product families)	for MOST possible product variants of ALMOST ALL product families BOM and/or PS are automatically generated	C or S or TS use software to choose the MAIN characteristics of the products and to control their compatibility (at least for the MOST IMPORTANT product families)	We have a production planning and control system that assures a very good service level at the subsequent stage (...) and maintains working capital (...) at a very low level	We know how much of each product is available to promise both in our stocks and in production and, even in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	(1) .... *AND* (2) .... *AND* (3) .... *AND* (4) A system is in place to continuously improve the speed and efficiency of the autonomous units in processing parts/product families	(1) Set-up times are VERY SHORT *AND* (2) Reductions of process set-up times are achieved by ...*idem* ... AND by application of special tools ...*idem* ...	for ALMOST ALL possible product variants of ALL product families BOM and/or PS are automatically generated	C and/or S use a software to choose ALL of the characteristics of the products and to control their compatibility (for ALL or ALMOST ALL of the product families)	We have a production planning and control system that assures an optimal service level at the subsequent stage (...) and maintains working capital (...) at an optimal level	We know exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Maturity level of the company in the given grid area

SKIPPED *Grid area skipped because workshop participants considered this area irrelevant to their company*

Maturity level of the company in the first assessment

Company is currently in between the maturity levels in a given grid area

Grid area where advancement has been recorded

Company is now in transition from one maturity level to another in the given grid area

Company is still in transition from one maturity level to another in the given grid area

Advanced maturity level

Figure 22. Long-term evaluation of the MC maturity level for the assembly lines product family – Metalmeccanica SPA

2.6.2 MC maturity grid long-term observational evaluation in Soft Automation SPA

For the first part of the long-term observational evaluation, a set of questions was used (Table 30) to reconstruct the story of the application of the generated implementation plan, as well as the overall impact the MC maturity grid had on Soft Automation SPA.

Table 30. Results of the long-term observational evaluation in Soft Automation SPA

Question	Summarized answers
How and why did the company agree to participate in the MC maturity grid assessment?	- The company had problems with presenting its product assortment to customers and with getting new customers
How did you choose the participants?	- The participants were chosen among the senior management staff of the company. Thus, they were people with technical knowledge of the products and processes as well as the power to determine and implement changes
From today's perspective, did the assessment using the MC maturity grid provide a good overview of the status of variety/customization management in your company?	- Yes - The assessment made workshop participants aware of the company status regarding the MC
Was the assessment efficient?	- Yes. Doing the assessment on so many aspects of MC in one single workshop is a great advantage of the developed grid
Did the grid help in breaking barriers, building consensus and taking responsibility?	- Yes - Some problems that were previously without an answer were seen as solvable. Agreement among various top management personnel was made possible
What were the main issues pointed out by the analysis?	- The complexity of the issues we are facing with providing customized products - The necessity to have a holistic approach to company advancement - Interdependencies within the grid areas
Can you remember the generated implementation plan?	- Participants could not remember the exact generated implementation plan, but during the discussion, all of the ideas that were generated were restated and expanded. This means that the original plan was probably augmented in the course of time and merged with other company activities and managers' and engineers' thought processes
Was the grid used after the first assessment? If yes, how frequently, for how long?	- Yes - It was used for a period of one year

If it was used, for what purposes was it used?	- The grid was used for training purposes of top management for one year after the assessment in order to absorb the ideas the grid provides
Was the generated plan implemented?	- Most of the generated plan was implemented - The SME is still working on some of the ideas generated because these ideas need more time to be implemented
Did you use external support to implement the plan?	- Yes. The company used the support of an external consultant. The consultant was used for training in change management and final shaping of the generated implementation plan
Do you think your experience with the MC maturity grid changed something in the presentation of your product assortment, in the way you see the company, in the organization of the production, and so on?	- Yes - Product assortment is today presented in a completely different way. Presentation is very fast and understanding from the potential customers' side is immediate. This is a product of the grid and the overview of MC complexity it provided - The whole company is now looked at from the perspective of product families and product platforms

Notably, focusing on product families and product platforms enabled the company to reach an understanding of the need for different employee competences for different parts of the product assortment. This made the training time for new employees much shorter and more cost effective.

In the discussion, the overview of the realized ideas was done (Table 31). In the end, one generated idea was completely implemented, while two other ideas are in the process of realization because they require much longer realization time.

Table 31. Realization of the ideas generated in the implementation plan in Soft Automation SPA

Real. order	Idea	Priority	Impact	Effort	Interdependence	Realized
-	Formalize the product families; classify and study the product trends; and analyze the market opportunities for the current products (grid area 5)	N/S	L – in the short term H – in the long term	L	Positive effect on grid area 10 Sales configurator	YES
-	Determine the activities that compose products/services and list them (grid area 10)	N/S	M – in the short term	L – for energy plants H – for the whole product assort-ment	Positive interactions with 5 Product space organized in clearly distinguished product families	IN PROCESS
-	Modularize the high-level software and manufacturing execution systems (MES) (grid area 6)	N/S	H – when imple-mented	M	Positive interactions with 10 Sales configurator	IN PROCESS
Legend: L – Low; M –Medium; H – High; VH – Very High; N/S – Not specified						

In the final step of the long-term observational evaluation, the company staff was asked to make a current assessment of the company as-is situation. The assessment showed that Soft Automation SPA made advancements in all three grid areas where ideas were generated: grids areas 5, 6 and 10 (Figure 23). In addition to this, advancement in maturity levels were recorded in grid areas 2 and 3 (Figure 23).

Grid area =>	1	2	3	4	5	6	7	8	9	10	11	12
Maturity level ‖ V	Standardization of parts: Periodic rationalization to eliminate parts no longer needed	Standardization of parts: Day-by-day limitation of new parts introduction	Standardization of production sequences	Grouping of parts into part families through a similarity-based classification system SKIPPED	Product space organized in clearly distinguished product families	Product modularization	Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families SKIPPED	Low and continuously reduced set-up times SKIPPED	Technical configurator	Sales configurator	Keeping stocks at optimal levels SKIPPED	Sophisticated and dependable supports for determining available to promise SKIPPED
1	Never done	NO attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff and (2) the organization	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	Products are not clustered in product families	No modularization at all	Machines are clustered on the shop floor based on their functional similarity	We do not have a clear view of set-up times because we have never considered them	BOMs and PSs (if present) are manually defined possibly by modifying similar BOMs/PSs *(BOM - bill of materials PS - production sequence)*	Customers, salesmen and the technical-sales employees (CSTS) do not have any structured support to choose the specific characteristics of the product and to control their compatibility	We do not have a production planning and control system that assures an acceptable service level at the subsequent stage *(production of parts, assembly of final products or delivering product to the customer)* and maintains working capital *(finished products, modules, components, parts and raw materials)* at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stocks or are in production are available to promise
2	We standardized the parts and we eliminated parts no longer needed *BUT* this was an isolated initiative	Attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff (2a) NO parts standardization guidelines (2b) NO SW supports for part standardization	(1) It is easy for design/production engineers to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	(1) Parts ARE grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes), (2) The criteria used are NOT FORMALIZED and coincide with the production and design engineers' experience	(1) A PORTION of the product assortment is composed of products clustered in product families according to similarities in product functions and product-related production processes (2) But the way the clustering is obtained is NOT GUIDED by design procedures	(1) In SOME of our product families, all of the products have been thought about such that each product function is performed by a specific chunk (module) and is not performed through interaction with more chunks	(1) Machines and assembly stations are able to process different parts/products (within a family) with similar efficiency *AND* (2) Machines and assembly stations are clustered based on the part/product families to which they are dedicated	(1) Set-up times are VERY LONG *AND* (2) No systematic reductions of set-up times are being applied	for A LOT of possible product variants of SOME product families BOM and/or PS are automatically generated	CSTS have a structured support (without SW) to choose ... and control ...	We have a production planning and control system that assures an acceptable service level at the subsequent stage (...) and maintains working capital (...) at an acceptable level	We know how much of each product is available to promise both in our stocks and in production but in the latter case, we are not really dependable regarding when they will be available in the warehouse. if the product is not yet launched into production, we apply some fixed lead times that are common for several products for the promise
3	(1) There is a systematic procedure to eliminate parts no longer needed *AND* (2) This procedure is periodically done on SOME part families	(1, 2a) Part standardization guidelines for design/production engineers and purchasing staff exist and are SOMEHOW applied, (2b) NO SW support	(1) .... *AND* (2) There are rules and SW support to limit the introduction of new production sequences	(1) .... *AND* (2) Part families are formed through a FORMALIZED and structured MANUAL classification system	(1) A CONSIDERABLE PORTION of the product assortment is ... *idem* ... (2) The way the clustering is obtained is GUIDED by design procedures (3) The distinction between product families is good, but can still be improved considerably	(1) We designed ALL of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	(1) .... *AND* (2) .... *AND* (3) The positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through them	(1) Set-up times are NEITHER LONG NOR SHORT *AND* (2) Reductions of process set-up times are achieved by continuous analysis of and changes made in: used technology (use of machines with low set-up times, fasteners, positioning aids, standardized tools,etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) OR by application of special tools (dedicated to part families and/or product families)	for MOST possible product variants of ALMOST ALL product families BOM and/or PS are automatically generated	C or S or TS use software to choose the MAIN characteristics of the products and to control their compatibility (at least for the MOST IMPORTANT product families)	We have a production planning and control system that assures a very good service level at the subsequent stage (...) and maintains working capital (...) at a very low level	We know how much of each product is available to promise both in our stocks and in production and, even in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	(1) .... *AND* (2) This procedure is periodically done on ALL part families	(1, 2a) Guidelines for design/production engineers and purchasing staff exist and are applied very RIGOROUSLY, (2b) SW support exists	(1) .... *AND* (2) .... *AND* (3) We make production sequences that differentiate products as late as possible	(1) .... *AND* (2) Part families are formed through an AUTOMATIC (SW) classification system	(1) THE WHOLE product assortment is ... *idem* ... (2) ...*idem* ... and these design procedures are DEEPLY ABSORBED by the whole organization (3) Product families are CLEARLY DISTINGUISHED and do not overlap each other	(1) .... *AND* (2) Our modules may have a longer life than single product families (product platforms exist)	(1) .... *AND* (2) .... *AND* (3) .... *AND* (4) A system is in place to continuously improve the speed and efficiency of the autonomous units in processing parts/product families	(1) Set-up times are VERY SHORT *AND* (2) Reductions of process set-up times are achieved by ...*idem* ... AND by application of special tools ...*idem* ...	for ALMOST ALL possible product variants of ALL product families BOM and/or PS are automatically generated	C and/or S use a software to choose ALL of the characteristics of the products and to control their compatibility (for ALL or ALMOST ALL of the product families)	We have a production planning and control system that assures an optimal service level at the subsequent stage (...) and maintains working capital (...) at an optimal level	We know exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

- *Maturity level of the company in the given grid area*
- *Company is currently in between the maturity levels in a given grid area*
- *Company is still in transition from one maturity level to another in the given grid area*
- SKIPPED — *Grid area skipped because workshop participants considered this area irrelevant to their company*
- *Grid area where advancement has been recorded*
- *Advanced maturity level*
- *Maturity level of the company in the first assessment*
- *Company is now in transition from one maturity level to another in the given grid area*

Figure 23. Long-term evaluation of the MC maturity level of Soft Automation SPA

2.8 Final remarks

The development of the MC maturity grid started from the literature review findings and followed the methodology for maturity grid development from Maier, Moultrie and Clarkson (2012). This methodology gave the main structure to the research, but it was kept flexible as the authors of the methodology themselves suggested. As a result, through an iterative interview process with managers, consultants and academics, great advances were made from the initial version of the MC maturity grid (Figure 8) to the second version of the MC maturity grid (Figure 11). The development process has proven to be an effective one, providing an opportunity to embed the voice of practice and academia in the same tool.

In the process of grid assessment, the *MC maturity grid observational evaluation* had six expected benefits listed at the beginning of the process (subsection 2.4). Those six expected benefits are listed again here, with an analysis of the success during the observational evaluation:

1. *Learn about the grid areas of the MC maturity grid*
   Metalmeccanica SPA and Soft Automation SPA are providing customized products to the market, but knowledge of the mass customization concept has not been part of the companies' know-how. The two companies were aware of standardization, modularization, classification, product families, and so on, but the interdependencies of the grid areas were out of the reach and comprehension of the companies. During the evaluation, the companies acquired new knowledge about the various grid areas and became aware of many interdependencies among the different MC enablers encompassed in the grid areas. The long-term observational evaluation showed that this knowledge enabled a better understanding of products and processes in the companies.

2. *Learn about the maturity levels of the various grid areas*
   During the MC maturity grid observational evaluation, the two SMEs acquired new knowledge about the various maturity levels of the grid areas. Although the concepts of standardization, modularization, sales configurators and so on were not new to either of the company's staff, the interdependencies between various maturity levels of different grid areas presented a significant upgrade to the companies' current knowledge.

3. *Gain awareness about the status of the company in the various grid areas*
   The MC maturity grid did promote an exchange of ideas and learning about the MC status of the two companies. Lively discussion and focusing on one grid

area at a time proved to be very good practices for generating useful, meaningful and feasible ideas for the SMEs.

4. *Involvement of employees in brainstorming about the possible advancements of the company in the various grid areas*
   Although the MC maturity grid does not provide any pre-made solutions for the company situation, with the proper guidance it provides a number of stimuli for the company staff to activate their knowledge about the company processes and the problems that exist in company functioning. Ideas were generated in both companies in around half the grid areas and these were in grid areas with low maturity levels, suggesting that the grid is efficient for promoting the generation of ideas for advancement.

5. *Identify advancements at the various levels that are meaningful for the current MC status of the company*
   During the MC maturity grid observational evaluation, companies were not pushed to implement 'perfect' and ideal solutions from any of available theoretical models. Instead, going through the grid areas, company staff identified weak spots in their own organization and with the guidance of the research team, proposed solutions that are close to their understanding, were meaningful from their point of view and were feasible to implement in the near future. This point was emphasized from the company staff's point of view in Metalmeccanica SPA: 'We have no resources to make everything at the same time, so we have to start from one, then the second, the third... In this way we can afford it, otherwise no'.

6. *Prioritize MC improvements*
   In the evaluation procedure, the generated ideas were prioritized. After prioritization of ideas, company staff in both companies agreed to implementation plans for realizing the ideas without any problem. These plans represent practical MC implementation plans for each of these companies.

After the observational evaluation and another round of interviews with managers, consultants and academics, the *refinement of the MC maturity grid* was conducted. The refinements referred to:

- Appropriateness of maturity levels – In order to enhance the usability of the grid, new assessment positions were introduced, namely: in-between level positions and transition positions. Furthermore, the assessment was separated for each product family. Also, an additional level was added to grid area 1 and to grid area 8, making the MC maturity grid symmetrical.

- Changing the sequence of the grid areas in the MC maturity grid – A new sequence of grid areas was introduced, moving ‘Product modularization’ to position 6 and ‘Grouping of parts into part families through a similarity-based classification system’, and ‘Product space organized in clearly distinguished product families’ one place up.
- Changing the cell text – The cell text was refined in a several ways. Firstly, the use of emphasized (uppercase) words was introduced. Secondly, the amount of cell text was reduced. Thirdly, the cell text was rearranged into small paragraphs where possible. Finally, the notion of ‘scaled product families’ was removed from grid area 5.

Finally, the *long-term observational evaluation* was conducted after almost three years. This evaluation answered three specific questions:

- *Was the generated implementation plan followed by the company?* – Both SMEs followed the generated implementation plans to a high extent. Notably, the research team recorded a tendency to merge the plan and the ideas for advancements it contained with the knowledge of company experts. In addition, plans were upgraded and improved if needed when company staff acquired new information. This is recognized as a natural way of advancement for SMEs, which are flexible in how they do business.

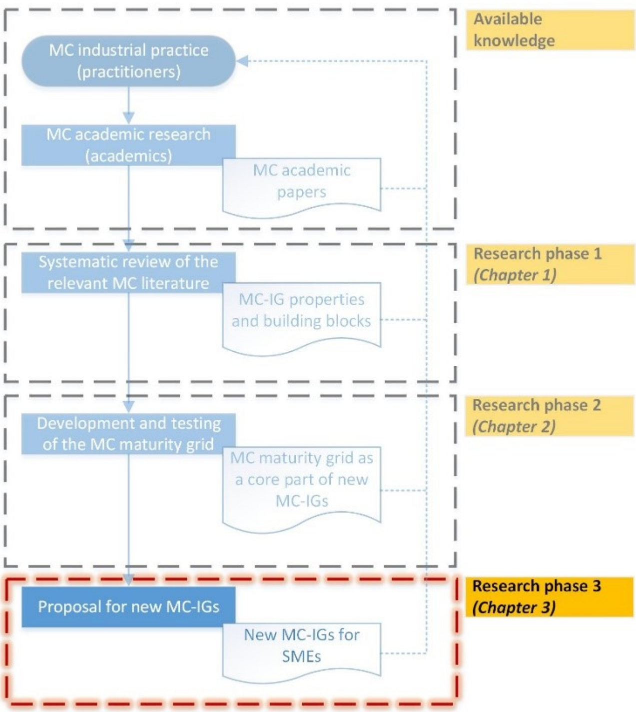
- *Were advancements made in the company’s MC status in almost three years?* – A number of advancements were made by the two SMEs in the period of almost three years. The companies made advancements either on their own or with the help of an external consultant (not related to the research team). Besides the advancements proposed during the group workshop and incorporated in plans for each company, there were also advancements recorded in other grid areas and product families that were not covered by the implementation plan. For example, although there were no plans made for advancement for the assembly lines product family of Metalmeccanica SPA during the workshop, this product family’s maturity level advanced in five grid areas. The effect of the group workshop on the generation of these advancements is to be further researched (the interviews need to be more deeply analyzed). But, since the manager of this product family was present in the workshop and the ideas generated during the workshop were successfully implemented, the influence of the MC maturity grid and the group workshop cannot be excluded.

- *Is the developed MC maturity grid capable of recording changes that occurred in the MC status of the companies?* – The developed MC maturity grid has proven to be capable of recording changes that occurred in the MC maturity level of both SMEs. This means that grid can record advancements in the MC maturity level of the companies that occurred in relatively short period of time (Figure 20, Figure 21, Figure 22 and Figure 23).

In conclusion, in Chapter 2 the MC maturity grid was developed using the method of Maier, Moultrie and Clarkson (2012) (Table 18). Next, the MC maturity grid was tested in two SMEs, one from the manufacturing sector and one from the service sector. The testing was first done through observational evaluation, where the MC maturity grid has proven capable of generating an MC implementation plan for the company. The second round of testing was conducted through a long-term observational evaluation in the same two SMEs, which, in turn, validated the effectiveness of the MC maturity grid in the long run. The tested and refined MC maturity grid (Figure 19) and the procedure developed for the MC maturity grid's use (Figure 12), as the main results of the second research phase, have been used as a basis to deliver a proposal for the new MC implementation guidelines for SMEs (Chapter 3).

CHAPTER 3: Proposal for new MC implementation guidelines

Chapter Summary



In the third part of the research, new MC implementation guidelines for SMEs are developed. The findings from the previous two phases of this PhD research are used in this phase to develop new MC implementation guidelines based on the MC maturity grid. More specifically, the improvement opportunities for the MC implementation guidelines have been applied to establish a number of characteristics and properties in the new guidelines. The MC implementation building blocks identified in the first part of the research have been used as a reference framework to structure the new guidelines. Finally, the MC maturity grid developed and tested in the second part of the research has been set as a core tool that supports the application of the guidelines.

3.1 Method for development and evaluation of the new MC implementation guidelines

Development of the new MC-IGs has been done based on the findings of the PhD research, namely the literature review and the empirical application of the MC maturity grid.

The main findings taken from the literature review are the seven identified MC-IG building blocks, the identified MC-IG properties, and the improvement opportunities for MC-IGs. More specifically, MC-IG building blocks have been used as a reference framework to develop and structure new MC-IGs for SMEs.

The MC-IG building blocks have been operationalized through the gathering of data from the literature and analytical reasoning about the data obtained through the development and testing of the MC maturity grid. In this way, new MC-IGs once more combine knowledge from academia and from practice. In the next sub-chapter, a proposal for MC-IGs for SMEs is presented.

3.2 Proposal for new MC implementation guidelines for SMEs

3.2.1 MC implementation guidelines for SMEs: A new proposal

In order to proceed with the proposal for new MC implementation guidelines for SMEs, I recall that, in section 1.3.1, MC-IG building blocks were defined as seven coding dimensions that address the content of MC-IGs (Figure 4). I also recall that based on these MC-IG building blocks, a definition of MC-IGs was proposed:

> *Mass customization implementation guidelines (MC-IGs)* are intended to guide company transformation towards MC. They do so by providing:
>
> - An overview of MC
> - The applicability context of the IGs
> - As-is analysis tools to assess the current company situation
> - Exemplified implementation instructions of MC enablers
> - Required resources for implementation of MC enablers
> - Factors that may hinder implementation of MC enablers

Thus, the MC-IG building blocks identified in the literature review (with the MC-IG definition) represent the framework used for the new MC-IGs proposal. I further present the MC-IG building blocks of the proposed MC-IGs for SMEs:

Mass customization overview

Definition of MC:

- Mass customization (MC) is defined as an organization's ability to provide customized products and services that fulfil each customer's idiosyncratic needs without considerable trade-offs in cost, delivery and quality (Pine II 1993; Liu, Shah, and Schroeder 2006; Squire et al. 2006).

Definitions of the addressed enablers:

- *Group technology* is a design, manufacturing and organization approach used to manage diversity through a similarity-based grouping of parts, products and design/manufacturing activities (Kusiak 1987; Burbidge 1992; Wemmerlöv and Johnson 1997; Selim, Askin, and Vakharia 1998; Xu, Zhang, and Huang 2014). Application of group technology may vary from informal, relying on part/product/activity similarities, to full introduction of manufacturing cells on the shop floor (Hyer and Wemmerlöv 1982; Kusiak 1987; Wemmerlöv and Hyer 1989; Burbidge 1992). When implemented, group technology may lead to a reduction of setup times, throughput times, work-in-process inventories and response time to customer orders (Wemmerlöv and Hyer 1989; Wemmerlöv and Johnson 1997).

- *Part standardization* is a design and manufacturing approach in which several different components of one product/several products/product generations are replaced by a common component that can perform the functions of all of the components it replaces (Perera, Nagarur, and Tabucanon 1999; Swaminathan 2001; Caux, David, and Pierreval 2006). Part standardization mitigates the effects of product proliferation on product and process complexity (Swaminathan 2001; Heese and Swaminathan 2006), reduces inventories (due to risk pooling) and lead-time uncertainty (Ma, Wang, and Liu 2002; B. Yang, Burns, and Backhouse 2004), reduces the level of safety stocks required to meet the service level (Baker 1985; Hillier 1999; Hillier 2002a; Hillier 2002b), reduces manufacturing costs through economies of scale (Fong, Fu, and Li 2004) and so on.
- *Product modularization* is a product design concept in which products from one product family are partitioned into highly independent (or loosely coupled) and preferably function-specific product components (modules) with standardized component interfaces and high component combinability (Sanchez and Mahoney 1996; Baldwin and Clark 1997; Duray et al. 2000; Schilling 2000; Langlois 2002; Salvador, Forza, and Rungtusanatham 2002a; Hsuan Mikkola, and Skjøtt-Larsen 2004; Salvador 2007). Product modularization reduces component variety while increasing the number of end-product variants without incurring a substantial negative impact on operational performance (Duray et al. 2000; Salvador, Forza, and Rungtusanatham 2002a). Design activities and product configuration activities are facilitated once a product has been modularized (Salvador, Forza, and Rungtusanatham 2002a).
- *Product platform development* refers to defining a set of design parameters, features and components that form a common structure from which a stream of derivative products (product family/families) can be efficiently developed and produced (Meyer and Lehnerd 1997; Robertson and Ulrich 1998; Muffatto 1999; Gonzalez-Zugasti, Otto, and Baker 2000; Simpson, Maier, and Mistree 2001; Simpson 2004). Utilization of product platforms reduces product development time, system complexity and development and production costs; improves the ability to upgrade products and so on (Meyer and Lehnerd 1997; Muffatto 1999; Simpson 2004).
- *Information technology (IT)-based product configuration* refers to a set of IT-backed activities that support order acquisition and fulfilment by translating each customer's specific needs into correct and complete product information using a fixed set of well-defined product components and predefined component interactions (Sabin and Weigel 1998; Forza and Salvador 2008;

Trentin, Perin, and Forza 2012). Information technology-based product configuration guides users in defining adequate and feasible product variants, supplies users with real-time information on the overall characteristics of the product configuration and automates the generation of production data (e.g. BOM, production sequences, production drawings, etc.) (Forza and Salvador 2002; Steger-Jensen and Svensson 2004; Forza and Salvador 2008), and so on.

- *Form postponement* 'means delaying the commitment of resources to the final configuration of a product as long as possible' (Trentin et al. 2011, 1977, built upon Alderson 1950 and Heskett 1977). Form postponement reduces the risk and associated costs of specifying the wrong variety mix in a forecast-driven manufacturing environment (Alderson 1950; Bucklin 1965; Zinn and Bowersox 1988; Whang and Lee 1998; Aviv and Federgruen 2001; S. Kumar and Wilson 2009), while in an order-driven manufacturing environment, customer input on product differentiation features is required later along the order fulfilment process (Forza, Salvador, and Trentin 2008).
- *Virtual build to order* (VBTO) 'is a form of order fulfilment system in which the producer has the ability to search across the entire pipeline of finished stock, products in production and those in the production plan, in order to find the best product for a customer' (Brabazon and MacCarthy 2004, 155). This approach reduces the trade-off between customization, delivery lead-time and working capital.
- *Single minute exchange of die* (SMED) 'refers to a theory and techniques for performing setup operations in under ten minutes, i.e., in a number of minutes expressed in a single digit. Although not every setup can literally be completed in single-digit minutes, this is the goal of ... [SMED], and it can be met in a surprisingly high percentage of cases. Even where it cannot, dramatic reductions in setup time are usually possible' (Shingo 1985, xix)
- *Mixed-model assembly line* is an assembly line capable of producing 'units of different models in an arbitrary inter-mixed sequence' (Becker and Scholl 2006, 696, based on Bukchin, Dar-El, and Rubinovitz 2002)

Applicability context of the guidelines

The present MC implementation guidelines have been specifically designed for SMEs. Given the chosen context, a greater emphasis has been given to basic enablers of MC such as parts standardization. Given that SMEs are affected by a lack of resources, the guidelines have been designed to demand few resources. Furthermore, empirical tests have shown that the core part of the guidelines (the MC maturity grid) is effective in

SMEs, both for assessing MC maturity levels and for generating MC implementation plans.

Until now, the MC maturity grid has been tested only in SMEs. Thus, the possibility for generalization and application to large enterprises is unknown. It is probable that the MC maturity grid could be useful for lower level management in large enterprises, since management at this level has more specific technical knowledge compared to upper level management, where knowledge of business strategy is more emphasized.

Required resources

Estimation of the resources required for implementation is done in the idea generation phase of the procedure for use of the MC-IGs (Figure 26). For this estimation, company staff applies its knowledge of company business and the available resources.

Although a precise calculation of the resources required is not possible with this procedure, the benefits of reaching an estimation of needed resources by a consensus of company staff and in a short time have proven to be well accepted and suitable for SMEs.

As-is analysis tools

The MC maturity grid is designed and developed as an as-is analysis tool (Figure 24). The empirical applications have shown that the MC maturity grid is effective for determining the as-is situation of SMEs with regard to MC. Furthermore, the MC maturity grid has proven to be capable of recording long-term changes in the MC maturity level of companies after MC initiatives have been implemented.

Grid area => Maturity level II V	1 Standardization of parts: Periodic rationalization to eliminate parts no longer needed	2 Standardization of parts: Day-by-day limitation of new parts introduction	3 Standardization of production sequences	4 Grouping of parts into part families through a similarity-based classification system	5 Product space organized in clearly distinguished product families	6 Product modularization	7 Organizing machines/assembly stations on the shop floor in order to maximize the speed and efficiency of processing part/product families	8 Low and continuously reduced set-up times	9 Technical configurator	10 Sales configurator	11 Keeping stocks at optimal levels	12 Sophisticated and dependable supports for determining available to promise
1	Never done	NO attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff and (2) the organization	No attention is paid to production sequence proliferation by the organization and by the individual design and production engineers	Parts are not grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes)	Products are not clustered in product families	No modularization at all	Machines are clustered on the shop floor based on their functional similarity	We do not have a clear view of set-up times because we have never considered them	BOMs and PSs (if present) are manually defined possibly by modifying similar BOMs/PSs (*BOM - bill of materials PS - production sequence*)	Customers, salesmen and the technical-sales employees (CSTS) do not have any structured support to choose the specific characteristics of the product and to control their compatibility	We do not have a production planning and control system that assures an acceptable service level at the subsequent stage *(production of parts, assembly of final products or delivering product to the customer)* and maintains working capital *(finished products, modules, components, parts and raw materials)* at an acceptable level	It is difficult for us to say whether or not the products that are available in the finished products stocks or are in production are available to promise
2	We standardized the parts and we eliminated parts no longer needed *BUT* this was an isolated initiative	Attention is paid to parts proliferation by: (1) design/production engineers and purchasing staff (2a) NO parts standardization guidelines (2b) NO SW supports for part standardization	(1) It is easy for design/production engineers to reuse the same sequences (because the production sequence database is well organized and because production sequences are grouped in classes)	(1) Parts ARE grouped in families using similarity-based classification criteria (shape, size and materials, and therefore production processes), (2) The criteria used are NOT FORMALIZED and coincide with the production and design engineers' experience	(1) A PORTION of the product assortment is composed of products clustered in product families according to similarities in product functions and product-related production processes (2) But the way the clustering is obtained is NOT GUIDED by design procedures	(1) In SOME of our product families, all of the products have been thought about such that each product function is performed by a specific chunk (module) and is not performed through interaction with more chunks	(1) Machines and assembly stations are able to process different parts/products (within a family) with similar efficiency *AND* (2) Machines and assembly stations are clustered based on the part/product families to which they are dedicated	(1) Set-up times are VERY LONG *AND* (2) No systematic reductions of set-up times are being applied	for A LOT of possible product variants of SOME product families BOM and/or PS are automatically generated	CSTS have a structured support (without SW) to choose ... and control ...	We have a production planning and control system that assures an acceptable service level at the subsequent stage (...) and maintains working capital (...) at an acceptable level	We know how much of each product is available to promise both in our stocks and in production but in the latter case, we are not really dependable regarding when they will be available in the warehouse. if the product is not yet launched into production, we apply some fixed lead times that are common for several products for the promise
3	(1) There is a systematic procedure to eliminate parts no longer needed *AND* (2) This procedure is periodically done on SOME part families	(1, 2a) Part standardization guidelines for design/production engineers and purchasing staff exist and are SOMEHOW applied, (2b) NO SW support	(1) .... *AND* (2) There are rules and SW support to limit the introduction of new production sequences	(1) .... *AND* (2) Part families are formed through a FORMALIZED and structured MANUAL classification system	(1) A CONSIDERABLE PORTION of the product assortment is ... *idem* ... (2) The way the clustering is obtained is GUIDED by design procedures (3) The distinction between product families is good, but can still be improved considerably	(1) We designed ALL of our product families in a modular way: We have families of modules (each function is performed by only one module) with standardized interfaces	(1) .... *AND* (2) .... *AND* (3) The positioning and organization of the machines/assembly stations minimizes the time the parts/products take to pass through them	(1) Set-up times are NEITHER LONG NOR SHORT *AND* (2) Reductions of process set-up times are achieved by continuous analysis of and changes made in: used technology (use of machines with low set-up times, fasteners, positioning aids, standardized tools,etc.) and organization (standardization of set-up procedure, using offline set-up, etc.) OR by application of special tools (dedicated to part families and/or product families)	for MOST possible product variants of ALMOST ALL product families BOM and/or PS are automatically generated	C or S or TS use software to choose the MAIN characteristics of the products and to control their compatibility (at least for the MOST IMPORTANT product families)	We have a production planning and control system that assures a very good service level at the subsequent stage (...) and maintains working capital (...) at a very low level	We know how much of each product is available to promise both in our stocks and in production and, even in the latter case, we are very dependable regarding when the product will be available in the warehouse
4	(1) .... *AND* (2) This procedure is periodically done on ALL part families	(1, 2a) Guidelines for design/production engineers and purchasing staff exist and are applied very RIGOROUSLY, (2b) SW support exists	(1) .... *AND* (2) .... *AND* (3) We make production sequences that differentiate products as late as possible	(1) .... *AND* (2) Part families are formed through an AUTOMATIC (SW) classification system	(1) THE WHOLE product assortment is ... *idem* ... (2) ...*idem* ... and these design procedures are DEEPLY ABSORBED by the whole organization (3) Product families are CLEARLY DISTINGUISHED and do not overlap each other	(1) .... *AND* (2) Our modules may have a longer life than single product families (product platforms exist)	(1) .... *AND* (2) .... *AND* (3) .... *AND* (4) A system is in place to continuously improve the speed and efficiency of the autonomous units in processing parts/product families	(1) Set-up times are VERY SHORT *AND* (2) Reductions of process set-up times are achieved by ...*idem* ... AND by application of special tools ...*idem* ...	for ALMOST ALL possible product variants of ALL product families BOM and/or PS are automatically generated	C and/or S use a software to choose ALL of the characteristics of the products and to control their compatibility (for ALL or ALMOST ALL of the product families)	We have a production planning and control system that assures an optimal service level at the subsequent stage (...) and maintains working capital (...) at an optimal level	We know exactly how much and when a specific product variant to be promised to a customer will be available in the warehouse and we are also able to modify the configuration of products already launched in production in order to be able to promise customized products at the earliest delivery date in a reliable way and without incurring additional production costs or decreasing the level of service to our customer

Figure 24. MC maturity grid

Hindrance factors

During the testing of the MC maturity grid in the SMEs, a couple of hindrance factors were recorded:

- Pace of assimilation of the MC concept – The pace at which company staff can grasp the MC concept could hinder the MC implementation. Future implementations could raise a need for additional workshops that follow MC-IG applications. Nevertheless, the empirical testing done up to now did not show a need for additional workshops in the case SMEs.
- Available human resources – For SMEs, any change project can take a relatively large effort. On the one hand, the proposed MC-IGs result in a generated implementation plan composed of incremental steps that can be performed in a number of smaller projects through a piecemeal approach. On the other hand, even this piecemeal approach requires consistency and a continuous effort from company staff in order to move towards MC. It is likely that in some cases SMEs will not follow through on the implementation plan on their own because of the overwhelming every day work obligations that would delay the implementation of the generated plan. In this case, the use of external consultancy that would supervise the realization of the generated implementation plan could be essential for the success of the MC implementation.
- Resistance to change or readiness to participate – Testing of the MC maturity grid has shown that a sceptical person in the group can be expected in some cases. Thus, a moderator who is in charge of the group workshop should be keen and capable of involving the sceptical person(s) in group discussions and idea generating.

Instruction contents

The MC-IGs for SMEs based on the MC maturity grid are not specific in the sense that they do not provide the exact instructions for MC implementation upfront. Rather, the guidelines, and the MC maturity grid as part of them, use a number of stimuli and reference points to spur discussion in the group workshop, to generate ideas and to guide the formation of the MC implementation plan. These reference points are the maturity levels in the twelve grid areas. Through group discussion, the maturity levels drive the workshop by stimulating company staff to produce concrete ideas for advancing in the specific grid area, that is, for moving from the current maturity level to a higher one in the grid area. In effect, the company will advance in the implementation of the nine MC enablers that are represented through the twelve grid areas of the MC maturity grid (Figure 10), with the intention to eliminate perceived overlaps between the enablers. Finally, ideas for advancements in specific grid areas are prioritized and sequenced and, in this way, the MC implementation plan is generated. Thus, the company is, in effect, provided with a sequenced MC implementation plan that enables it to select and implement certain MC enablers in order to further develop its MC capability.

Instruction exemplification

The MC-IGs offer examples in the form of cell text that describes the maturity levels in each MC maturity grid. These examples are generic, but were constructed in such a way that the company staff can easily recognize their own as-is situation.

The specificity of the grid area and grid cells stimulates the generation of examples. The company employees provide each other with examples about a given MC area or MC cell and these examples are mainly taken from their own company. Eventually, facilitators (MC experts) will take questions to provide examples that may be inspiring for the company participants in the specific point of discussion.

3.2.2 How to use the new MC implementation guidelines for SMEs

An important component of the MC-IGs is the procedure for their use (Figure 25). The procedure for use encompasses all of the steps for using the MC maturity grid. Thus, the majority of the steps of the procedure for use of MC-IGs have been empirically tested and validated.

In step 7 of the procedure for use of MC-IGs (Figure 25), ideas for advancement for every grid area should be generated. In order to make this process of idea generation more efficient, a template for generating ideas for advancements is proposed (Figure 26).

In order to generate the implementation plan in step 11 of the procedure for use of MC-IGs (Figure 25), a template for generating an MC implementation plan is proposed (Figure 27).

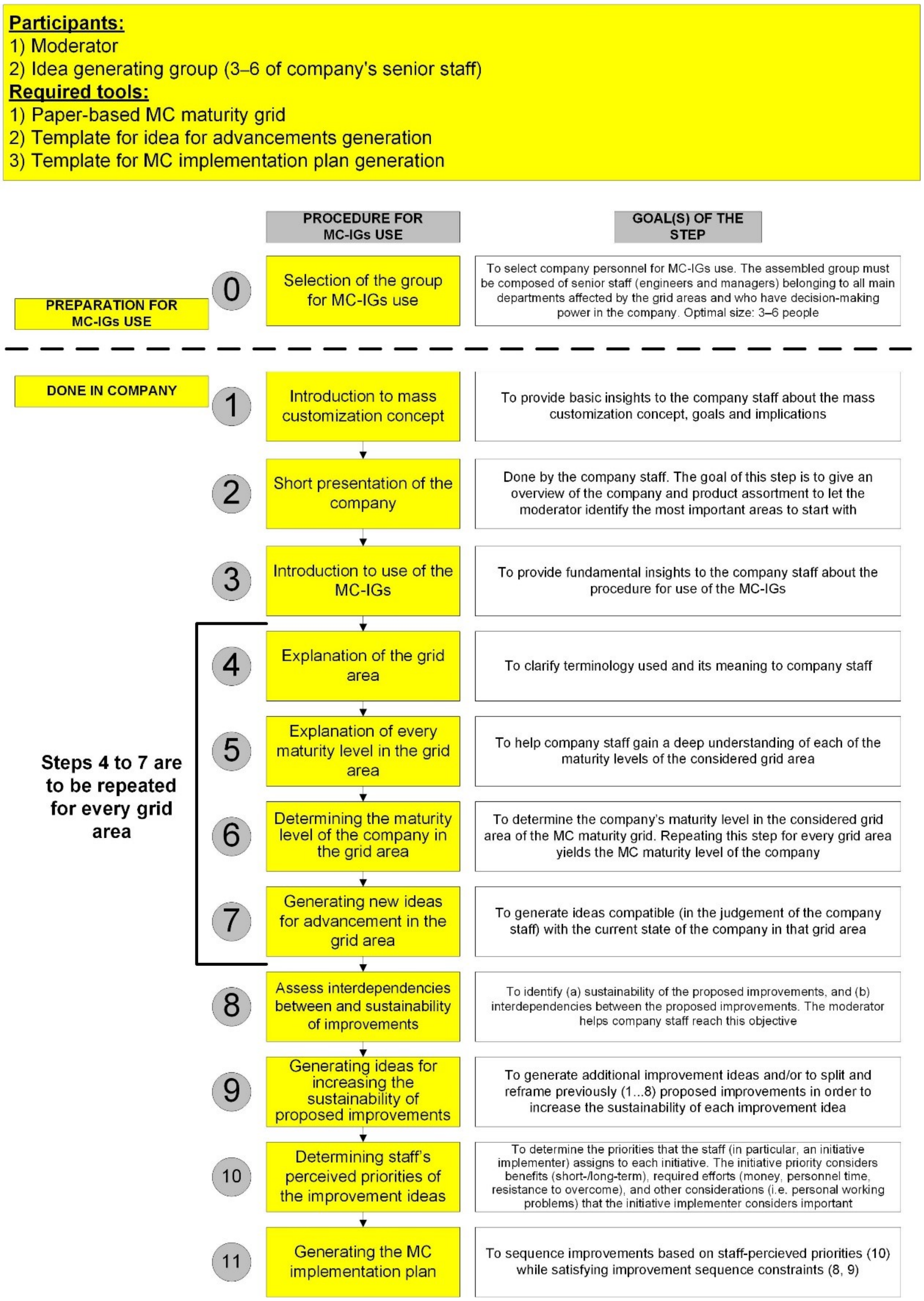


Figure 25. Procedure for use of MC-IGs

Idea description	Grid area	Priority	Impact	Effort	Interdependencies
Legend: L – Low; M – Medium; H – High; VH – Very High					

Figure 26. Template for generating ideas for advancements

Realization order	Idea	Priority	Impact	Effort	Interdependencies
1					
2					
3					
4					
5					
6					
Legend: L – Low; M – Medium; H – High; VH – Very High					

Figure 27. Template for MC implementation plan generation

3.3 Final remarks

Since it can be expected that the interested reader will look at the proposal for MC-IGs through the lens of a certain paradigm (i.e. having expectations of what IGs should look like), besides understanding what the proposed MC-IGs represent, it is also important to understand what they do not represent and what they do not intend to provide. In order to achieve this goal, I will start the final observations of this chapter with recalling the goal of the research: 'Develop guidelines to help SMEs select MC enablers and sequence them to develop MC capability'. Based on the research goal, one could expect the developed MC-IGs to be more prescriptive and to say something like: 'First standardize the parts, then introduce the sales configurator and afterwards modularize the products, etc.', which would, in effect, provide an implementation sequence for MC enablers. But, even though the literature review showed that some enablers, in general, should be implemented before others (Figure 3), tests of the MC maturity grid showed that it is important to leave the company to follow the path that is easier and/or more meaningful for it in order to make successful steps towards MC. For the purpose of deciding the right path towards MC implementation, the MC maturity grid provides an overview of the possible steps, which is often far ahead of the company's capabilities. This overview will help the company staff to specify the steps (e.g. 'define a commercial dialogue to guide the choices of sizing of the hydraulic power units') and to figure out possible sequences for implementation. Thus, the intention of the MC-IGs built on the basis of the MC maturity grid is not to prescribe a sequence for implementing MC enablers. Additionally, the intention of the proposed MC-IGs is not even to recommend that the company works on the grid areas that are found to be underdeveloped in the analysis (i.e. first or second maturity level in a specific grid area). It could be that the underdeveloped grid area is not especially rewarding for the company at the moment, or the company does not possess the scope to take it into consideration. Overall, the developed MC-IGs do not 'force' a company to implement any specific solution or enabler sequence. Instead, the goal of the developed MC-IGs is to generate a specific MC implementation plan for every SME, starting with a holistic assessment of the as-is situation of every company.

In the proposal for new MC-IGs for SMEs, all seven of the MC-IG building blocks identified in the literature review are taken into account. Firstly, the as-is analysis tools building block is provided through a developed tool in the form of the MC maturity grid. Secondly, three building blocks, namely MC overview, applicability context of the guidelines and hindrance factors are provided in written forms. Thirdly, two building blocks, namely required resources and instruction contents emerge as a result of using the MC maturity grid in a group workshop. Finally, the instruction exemplification building block is partially provided through the cell text in the MC maturity grid and partially emerges as a result of using the MC maturity grid in a group workshop.

Specifically, the MC overview provided the MC definition, list of MC enablers and definitions of MC enablers. Other MC overview components, namely a set of benefits derived from MC implementation, and a set of benefits derived from each MC enabler implementation, are partially provided through the MC definition and definitions of the MC enablers. These two sets of benefits are further elaborated and built on through group workshops and application of the MC maturity grid. The remaining two components of the MC overview, namely the basic MC enabler relationships and the list of departments involved in implementing MC, are gradually introduced through the group workshop. This gradual introduction is due to differences in the organization of SMEs and their departments, which are understood only through a deeper analysis of the case SME.

A full assessment of the new proposed MC-IGs for SMEs is beyond the scope of this dissertation. Assessment of the full guidelines requires a number of empirical assessments to be performed. Pondering these empirical assessments raises a number of questions; for example:

- What should be checked in the empirical assessment? – For example, the characteristics of the people that should be involved in use of the guidelines. These characteristics could be their function in the company, their role, the competences possessed by a person, attitude towards change, attitude towards working in groups and so on.
- How should the first meeting be prepared? – For example, what is the difference if the MC-IGs are used by managers themselves; by an external moderator with managers in a ‘one-shot’ procedure; or by an external consultant who would supervise the company all the way in implementing MC using the MC-IGs simply as coaching and training tools, and so on.
- How relevant is the size of the company to how the guidelines are used?
- What is the best scheduling for the group workshop? – Is ‘one-shot’ in a whole day good? Or, are two half-days better for performing the group workshop?
- What is the best way to take notes during the group workshop? – Experience with idea generation showed that if an idea is not written down the moment it is generated, it can be difficult to remember all of the necessary details. Thus, the question is whether one person should be dedicated to taking notes during the empirical assessment.
- How can the new MC-IGs be tested to determine whether or not they work? – Should an experiment with different ways of using the guidelines in similar companies be conducted? Or, should the guidelines be used in one preselected

way to see whether this way performs differently in different kinds of companies?

- And so on

Whatever the answers to the posed questions are, the fact is that the testing of the new MC-IGs for SMEs should be done in real organizations and over a longer period of time. Possibly, testing could be done in three phases:

- First, ask the opinions of consultants, managers and academics in a similar manner to how it was done for the MC maturity grid.
- Second, use the procedure in very different contexts in an exploratory study in order to understand its effectiveness, its limitations and the possibilities for improving it.
- Third, design a set of user cases or some experiments to test specific issues that the exploratory assessment signalled as important to be tested with a carefully planned design.

At this moment, an analysis of the next possible steps for testing and validating the developed guidelines is underway. Future directions for the continuation of this research will depend mainly on the nature of the answers to the questions posed.

Discussion and Conclusions

This chapter presents a summary of the main contributions of the research done in this dissertation. Further, limitations of the research are addressed. Finally, opportunities for future research are highlighted.

With the research objective of developing guidelines to help SMEs select MC enablers and sequence them to develop MC capability, the present dissertation brings contributions that can be divided in three groups. Each group of contributions comes from one of three research phases.

The first group of contributions of the present doctoral dissertation is the result of the review of MC-IG literature. This group of contributions adds to the theory of MC-IGs. The inductively developed classification scheme allowed the identification of the characteristics of the MC-IGs available in the MC-IG literature and to generate proposals for improving MC-IGs. Specifically, this scheme enabled identification of MC-IG properties, namely: a holistic property, a detailed and user-friendly description property, and a context-dependent property. Further, seven MC-IG building blocks were identified, namely: MC overview, hindrance factors, applicability context, required resources, as-is analysis tools, instruction contents, and instruction exemplification. Additionally, a number of proposals were generated for improving MC-IGs, for example: the applicability context of the guidelines could be improved through development of MC-IGs with a specific context in mind; a distinction could be made between the as-is analysis tools that are applied very quickly, providing an overview of the company with regard to MC, and much heavier tools that are very detailed and can help the company understand exactly which MC enablers to implement and how to implement them; the scope of the enablers addressed through 'single enabler' implementation instructions in future developed MC-IGs should be widened to consider the interdependence between enablers; the linearity of the MC-IGs recorded in the relevant articles could be challenged to take into consideration the specific situation in which a company is working and so on.

The literature review performed in the present doctoral dissertation complements the previous literature reviews on MC (Da Silveira, Borenstein, and Fogliatto 2001; A. Kumar, Gattoufi, and Reisman 2007; Fogliatto, da Silveira, and Borenstein 2012; Ferguson, Olewnik, and Cormier 2014; Sandrin, Trentin, and Forza 2014). Three of these five literature reviews cover overall MC[15] (Da Silveira,

[15] The first article with overall coverage—Da Silveira, Borenstein and Fogliatto (2001)—classified the available MC frameworks, discussed MC success factors and MC enablers as well as providing a general MC research agenda for the future. A decade later, the same group of authors (Fogliatto, da Silveira, and Borenstein 2012) reviewed the MC literature with a similar focus. In their second literature review, they covered the years from 2000 to

Borenstein, and Fogliatto 2001; A. Kumar, Gattoufi, and Reisman 2007; Fogliatto, da Silveira, and Borenstein 2012), while two of these reviews focus on a specific part of the MC research[16] (Ferguson, Olewnik, and Cormier 2014; Sandrin, Trentin, and Forza 2014). None of the five literature reviews focuses on MC implementation or MC-IGs.

Even though available literature reviews do not focus on the MC implementation process, they stress the importance of conducting research on this subject. So, when providing future directions for MC research, Da Silveira, Borenstein and Fogliatto (2001, 8) call for research in MC implementation, stating that 'Future research on MC should focus on the formulation of methodologies that enable rapid reconfiguration of existing organizational structures and processes into a mass-customized production system'. Although in their latter review, Fogliatto, da Silveira and Borenstein (2012, 22) do not restate the need for developing MC methodologies, they mention the issue of developing 'more effective solutions' compared to existing MC approaches, tangentially touching on the point of MC implementation guidelines. Sandrin, Trentin and Forza (2014, 159) stress that 'The importance of transforming organisations to pursue an MC strategy has been acknowledged since the introduction of the MC concept'. This 'transforming organizations to pursue an MC strategy' is synonymous with the MC implementation process. My research adds to these literature reviews by providing an overview of the MC implementation guidelines available in the MC literature, recognizing the building blocks of MC implementation guidelines and proposing a definition of MC-IGs that can be used as a basis for future research in the field of MC implementation.

Previous literature reviews also highlight that research on the MC implementation process is limited. Da Silveira, Borenstein and Fogliatto (2001, 11) conclude that 'there are several pending issues regarding its [mass customization's] practical implementation' and that 'literature on MC implementation is still incipient'. Da Silveira, Borenstein and Fogliatto (2001, 11) base these conclusions on the fact that 'Most claims are drawn from limited case examples or based on educated guesses from authors rather than from hard evidence obtained through exhaustive research'. A. Kumar, Gattoufi and Reisman (2007, 653) assert that 'there is a void of rigorous

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2010, updating their previous research, and once more identified research gaps for the future. A. Kumar, Gattoufi and Reisman (2007) provide a literature review with a historical perspective to understand the evolution of MC and MC research and stress the need to classify MC research.

[16] Two literature reviews that cover a narrower MC scope (Ferguson, Olewnik, and Cormier 2014; Sandrin, Trentin, and Forza 2014) differ regarding their focus. Sandrin, Trentin and Forza (2014) focus their research on MC organizational antecedents. Ferguson, Olewnik and Cormier (2014), instead, focus on the process of MC product development, which they analyze through the lenses of the marketing, engineering and distribution domains. Both Sandrin, Trentin and Forza (2014) and Ferguson, Olewnik and Cormier (2014) highlight future opportunities for research in their respective topics.

quantitative modeling and decision support in implementing mass customization strategy successfully and effectively', which supports the point that research on MC implementation is limited. Sandrin, Trentin and Forza (2014, 159) assert that in MC literature, 'relatively less attention has been paid to the organizational antecedents of MC … as compared with its technological enablers', stressing in this way the limited attention that has been focused on a specific part of the MC implementation endeavour. These conclusions are in line with the research findings of this doctoral dissertation that led to the relatively low number of articles retrieved from the MC literature that could be characterized as MC-IGs (20 articles).

The second group of contributions of this dissertation is the result of the developed MC maturity grid. The MC maturity grid was developed as a core component of future MC-IGs by applying the methodology of Maier, Moultrie and Clarkson (2012), named 'roadmap to develop new and evaluate existing maturity grids'.

The MC maturity grid introduces the possibility of a non-linear approach to MC implementation, in turn challenging the linearity of MC-IGs derived from the MC-IG literature (Figure 3). This linearity suggested in the literature provides a pre-set sequence of enablers that does not offer flexibility in deciding the sequence of the MC implementation steps. The development of the MC maturity grid started from the view that there could be various ways to achieve MC. In two observational evaluations and two long-term observational evaluations of the grid, the multiple ways to reach MC were observed in the following:

- The MC maturity grid does not indicate a specific area to work on. Obviously, the grid implicitly suggests that the weakest area should be considered for possible improvements. However, the choice to focus on a given area is deliberately left to the initiative of company users. In this way, they will signal initiatives that they feel they can and will carry out.
- The MC maturity grid does not state any specific sequence for the implementation of enablers. However, the grid makes company users aware of the main dimensions a company, very likely, sooner or later, has to work on to become a mass customizer.

Application of the long-term observational evaluation is a contribution to the MC-IGs substream because longitudinal studies, to the best of my knowledge, have never been used in this research substream. In the present work, long-term observational evaluation was used to determine the effect of the MC maturity grid after almost three years of application.

The developed MC maturity grid also presents a contribution to managerial practice. By merging inputs from literature findings, managers, consultants and academics to develop the grid, different viewpoints on what MC-IGs should look like have been taken into account. These viewpoints were further enhanced through two evaluations in SMEs. As a result, an artefact in the form of the MC maturity grid was created. Validation of the MC maturity grid showed that there are a number of characteristics of the artefact and its procedure for use that are beneficial for practitioners and hence directly contribute to practice:

- The A3 paper format that is easy to use – The A3 paper format has proven to be a good choice and suitable for group workshop use in SMEs. The A3 size of the grid, with 12 grid areas and 48 different maturity levels, immediately conveys the complexity of MC to the company staff. Nevertheless, the observational evaluations have shown that the grid is manageable for company staff and is suitable to work with.
- SME staff is able to quickly grasp the main idea of the MC maturity grid – After a short introduction, company staff is able to grasp the main idea of the grid areas and the maturity levels. Thus, there is a fast transition to the main activity of determining the MC maturity level of the company.
- Delivery of the group workshop in a short period of time – During a one-day workshop, participants were able to determine the MC maturity level of their SME, to generate ideas for advancement and to generate an implementation plan.
- The MC maturity grid generates lively group discussion, bringing new viewpoints to the various issues the company is facing – Evaluations in two SMEs showed that the grid produces lively discussion on various issues that are of interest for SME. To spur this discussion, the MC maturity grid provides a number of stimuli in the form of maturity level descriptions. These descriptions are used as reference points on which workshop participants can reflect in order to analyze their own company's as-is situation.
- Effective generation of ideas for advancement of the MC maturity level of the company – The MC maturity grid is successful at stimulating the generation of ideas for advancing the MC maturity level of a company that are incremental and affordable for the SME. These ideas are also close to company staff's thinking and highly relevant to the company staff because they are generated in the discussion about the issues the company is facing in its business.
- Effective generation of the implementation plan in a very short time – An implementation plan for advancement of the MC maturity level of the company is created easily and in a short time after the ideas for advancement have been generated. Rating the priority, impact, and effort of the advancement ideas, as

well as pondering their interdependencies with other ideas or grid areas, provides a sufficient base from which to create a realistic and usable MC implementation plan that is strongly based in the current as-is situation of the company.

- Training SME staff in the various aspects of MC – Through the use of the MC maturity grid, company staff undergoes training in the MC concept. This training results in a more holistic understanding of MC and a broader view of the problems induced by product variety and system complexity. Although it cannot be claimed that company staff immediately embrace the MC concept, a better understanding of MC was evident in both application cases.
- Flexibility in the use of the grid – Firstly, the MC maturity grid has proven to be highly adaptable in terms of the starting point for determining and discussing the company's MC maturity level. The main order of the grid areas can be used as a basic one, but if the main issues the company is facing are positioned in some specific grid areas, it is probably a better choice to start from those grid areas. The MC maturity grid has proven to be highly flexible in this respect. Secondly, the MC maturity grid has high flexibility in determining the exact maturity level in a specific grid area. This is due to the refinements, which ended with four options for determining the maturity level for each grid area, namely: determining the exact maturity level between the levels offered, determining the in-between position, determining the transition position in the grid area, and skipping the grid area. The flexibility of maturity level choice is even higher if we take into account that the transition position can be combined either with the exact maturity level or with the in-between position in the grid area.

The third group of contributions of the dissertation is a result of the proposal for new MC-IGs for SMEs. The MC maturity grid is the core part, while the MC-IG building blocks are core inputs of this MC-IGs proposal. The main contributions of the proposed MC-IGs for SMEs add to managerial practice as follows:

- New MC-IGs based on the maturity grid – To the best of my knowledge, these are the first implementation guidelines for implementation of mass customization developed on the basis of a maturity grid.
- Developed new MC-IGs based on MC-IG building blocks – The proposal for new MC-IGs for SMEs takes into account the identified MC-IG building blocks. In that sense, as far as the literature review has shown, these are the first MC-IGs that have been developed with previously identified characteristics of MC-IGs.

- The developed procedure for use of the MC-IGs – The developed MC-IGs for SMEs are accompanied with an elaborate procedure for their use (Figure 25). The main steps of the procedure have already been tested in practice through application of the MC maturity grid in two SMEs. It can be expected that, based on experiences of MC maturity grid application, new MC-IGs would be well accepted by practitioners.

Notably, the initial goal of the PhD research was to 'Develop guidelines to help SMEs select MC enablers and sequence them to develop MC capability'. One could expect that the developed MC-IGs would say 'First standardize the parts, then introduce the sales configurator and afterwards modularize the products, and so on'. Actually, the proposed MC-IGs based on the MC maturity grid do not provide this kind of help in a straightforward, high-level, strict and constrained way. More specifically, the result of the developed MC-IGs application can be, for example[17]: firstly, 'analyze the historical use of parts and create a system that will offer the main option and alternative options for some parts in the design process', which is much more limited and specific than 'standardize parts'; secondly, 'define a commercial dialogue to guide the choices of sizing of the hydraulic power units', which is much more specific than 'introduce product configurator'; and finally, conduct 'a study of modularization for Hydraulic Power Units family of products', which is much more limited and specific than 'product modularization', and so on. But, in another situation, given the specific situation and the willingness of the people responsible for the various areas of the company, the advancements could be planned in reversed order. So, the essential support that the guidelines based on the MC maturity grid provide is to guide a group of company staff through the key areas relevant to achieving or improving their company's MC capability, to find feasible steps that can be carried out and that they would like to do now and in the near future, at the same time building a shared view of what it means for their company to reach a high MC capability.

The present PhD research also has some *limitations*. One of the limitations of the research is the number of cases used in the observational evaluation and the long-term observational evaluation. On the one hand, only two empirical evaluations of the MC maturity grid as a core part of the new MC-IGs have been conducted. On the other hand, from 20 MC-IG articles found in the literature (Table 1), only 3 articles test-developed MC-IGs with two cases, while other MC-IGs were tested in one case or were not tested at all. Additionally, the MC maturity grid as a core part of the developed MC-IGs has been longitudinally assessed, which was not done in any of the

[17] Examples are taken from ideas for advancement generated in two SMEs in which the MC maturity grid was tested

20 reviewed MC-IG articles.

While some parts of the implementation guidelines, including the core ones, have been empirically assessed, the thorough and comprehensive empirical assessment of the entire MC-IGs has not been performed. Even though this implies more rounds of empirical assessment (and for this reason, it has not been set as something to push within the 3-year PhD), it is something to be done before diffusion and promotion of the guidelines. A rigorous assessment of the guidelines should be preceded by an exploratory assessment in different contexts in order to gain a deeper understanding of the behaviour of the guidelines when used under different conditions.

A limitation of the MC maturity grid could also be that the MC maturity grid alone is not enough for SME staff to assimilate the MC concept. One solution could be to develop additional training for company staff before or after the MC maturity grid has been applied in the company. A significant increase of MC understanding is also expected when the complete developed MC-IGs are presented to the company.

Finally, this PhD research opened *new opportunities for the future research* in the field of MC-IGs. Further research could be done on the generalizability of the MC implementation guideline building blocks and properties. This stream of research is important for defining standards for the future development of MC-IGs, and also of implementation guidelines in general.

The level of coherence between the maturity levels of the various grid areas, which was openly recognized by the company staff in the Soft Automation SPA, is one of the interesting topics to research. The issue of coherence leads directly to a very complex question of maturity-level configuration (i.e. configuration that is the result of determining maturity levels in all company-relevant grid areas. Please look at Figure 15, Figure 16 and Figure 17 for examples of configurations determined during the observational evaluation). Thus, the question of maturity-level configurations could be posed for: the minimum maturity levels needed in order for some advancement to become feasible; the optimal maturity levels needed in order to do something in the easiest and/or least resource-consuming way; and the most balanced configuration, which will aim to achieve an overall optimum across different grid areas. Notably, to cope with these maturity-level configurations, one should bear in mind the hefty 16,777,216 possible configurations with the current twelve grid areas and four maturity levels for each grid area in the MC maturity grid. Nevertheless, the maturity-level configurations are probably the next step in the research on proposed MC-IGs for SMEs. This step should begin with deeper research on balance between maturity levels in order to dig into the idea of maturity-level configurations.

The present PhD research also raised the issue of the behavioural component of acceptance of generated ideas by the managers in SMEs. Future research could investigate the acceptability of ideas that managers generate themselves compared to the acceptability of ideas that are provided to them from someone else (e.g. consultants, top management, etc.).

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Appendix – Definitions of MC enablers

- *Group technology* is a design, manufacturing and organization approach used to manage diversity through a similarity-based grouping of parts, products and design/manufacturing activities (Kusiak 1987; Burbidge 1992; Wemmerlöv and Johnson 1997; Selim, Askin, and Vakharia 1998; Xu, Zhang, and Huang 2014). Application of group technology may vary from informal, relying on part/product/activity similarities, to full introduction of manufacturing cells on the shop floor (Hyer and Wemmerlöv 1982; Kusiak 1987; Wemmerlöv and Hyer 1989; Burbidge 1992). When implemented, group technology may lead to a reduction of setup times, throughput times, work-in-process inventories and response time to customer orders (Wemmerlöv and Hyer 1989; Wemmerlöv and Johnson 1997).
- *Part standardization* is a design and manufacturing approach in which several different components of one product/several products/product generations are replaced by a common component that can perform the functions of all of the components it replaces (Perera, Nagarur, and Tabucanon 1999; Swaminathan 2001; Caux, David, and Pierreval 2006). Part standardization mitigates the effects of product proliferation on product and process complexity (Swaminathan 2001; Heese and Swaminathan 2006), reduces inventories (due to risk pooling) and lead-time uncertainty (Ma, Wang, and Liu 2002; B. Yang, Burns, and Backhouse 2004), reduces the level of safety stocks required to meet the service level (Baker 1985; Hillier 1999; Hillier 2002a; Hillier 2002b), reduces manufacturing costs through economies of scale (Fong, Fu, and Li 2004), and so on.
- *Product modularization* is a product design concept in which products from one product family are partitioned into highly independent (or loosely coupled) and preferably function-specific product components (modules) with standardized component interfaces and high component combinability (Sanchez and Mahoney 1996; Baldwin and Clark 1997; Duray et al. 2000; Schilling 2000; Langlois 2002; Salvador, Forza, and Rungtusanatham 2002a; Hsuan Mikkola, and Skjøtt-Larsen 2004; Salvador 2007). Product modularization reduces component variety while increasing the number of end-product variants without incurring a substantial negative impact on operational performance (Duray et al. 2000; Salvador, Forza, and Rungtusanatham 2002a). Design activities and product configuration activities are facilitated once a product has been modularized (Salvador, Forza, and Rungtusanatham 2002a).

- *Process modularity* refers to breaking down a large production process into smaller sub-processes that can be designed/redesigned and carried out autonomously (Sanchez and Mahoney 1996; Baldwin and Clark 1997; Feitzinger and Lee 1997; Blecker and Abdelkafi 2006). Process modularity provides a company with the flexibility needed to obtain effective mass customization (Feitzinger and Lee 1997), the possibility to re-sequence existing process modules or add new ones quickly in response to changing product requirements (Tu et al. 2004; Gualandris and Kalchschmidt 2013), and so on.
- *Product platform development* refers to defining a set of design parameters, features and components that form a common structure from which a stream of derivative products (product family/families) can be efficiently developed and produced (Meyer and Lehnerd 1997; Robertson and Ulrich 1998; Muffatto 1999; Gonzalez-Zugasti, Otto, and Baker 2000; Simpson, Maier, and Mistree 2001; Simpson 2004). Utilization of product platforms reduces product development time, system complexity and development and production costs; improves the ability to upgrade products and so on (Meyer and Lehnerd 1997; Muffatto 1999; Simpson 2004).
- *Information technology (IT)-based product configuration* refers to a set of IT-backed activities that support order acquisition and fulfilment by translating each customer's specific needs into correct and complete product information using a fixed set of well-defined product components and predefined component interactions (Sabin and Weigel 1998; Forza and Salvador 2008; Trentin, Perin, and Forza 2012). Information technology-based product configurations guide users in defining adequate and feasible product variants, supplies users with real-time information on the overall characteristics of the product configuration and automates the generation of production data (e.g. BOM, production sequences, production drawings, etc.) (Forza and Salvador 2002; Steger-Jensen and Svensson 2004; Forza and Salvador 2008), and so on.
- *Form postponement* 'means delaying the commitment of resources to the final configuration of a product as long as possible' (Trentin et al. 2011, 1977, built upon Alderson 1950 and Heskett 1977). Form postponement reduces the risk and associated costs of specifying the wrong variety mix in a forecast-driven manufacturing environment (Alderson 1950; Bucklin 1965; Zinn and Bowersox 1988; Whang and Lee 1998; Aviv and Federgruen 2001; S. Kumar and Wilson 2009), while in an order-driven manufacturing environment, customer input on product differentiation features is required later along the order fulfilment process (Forza, Salvador, and Trentin 2008).

- *Sourcing configuration for MC* refers to aligning the selection of customized product component suppliers (including the supplier's location and the company-supplier relationship) with the type of customized product family architecture practiced (component swapping vs. combinatorial modularity) (Salvador, Forza, and Rungtusanatham 2002b). If properly applied, sourcing configuration for MC can lead to high operational effectiveness in terms of time, cost and quality (Salvador, Forza, and Rungtusanatham 2002b).