Integrate Customer Order Decoupling Point and Mass Customisation Concepts: A Literature Review

Violetta Giada Cannas, Margherita Pero, Tommaso Rossi, and Jonathan Gosling

Abstract The postponement represents the key strategy for companies to achieve mass customisation. It is associated with the customer order decoupling point (CODP) positioning: the backward shifting, from a pure standardised configuration (i.e. make-to-stock (MTS)), allows companies to delay some supply chain activities until the customer order arrives, increasing product variety while maintaining efficiency. This concept has been widely analysed in the literature, but there is a lack of studies about the means to reach more standardisation starting from a pure customised configuration (i.e. engineer-to-order (ETO)). Nevertheless, the movement toward mass customisation benefits also ETO companies, by reducing costs and lead times while assuring flexibility, and represents a need in the high-competitive global markets. Therefore, this concept needs to be extended to a wider perspective that includes possible levels of customisation achievable from different configurations. This is possible through a good understanding of the CODP theory. This paper reviews the CODP literature to investigate the different existing perspectives and classify them in a structured framework. This framework compares the CODP literature with the mass customisation one, to understand what are the interconnections among them in the actual state of the art and what is missing to achieve a more general view of these concepts. This allows the study to open further research highlighting the recent trends and the uncovered topics.

Keywords Customer order decoupling point · Mass customisation · Postponement · Engineer-to-order

V. G. Cannas (✉) · M. Pero
Department of Management, Economics, and Industrial Engineering, Politecnico di Milano, Milan, Italy
e-mail: violettagiada.cannas@polimi.it

T. Rossi
School of Industrial Engineering, Carlo Cattaneo – LIUC University, Castellanza, Italy

J. Gosling
Logistics and Operations Management, Cardiff Business School, Cardiff University, Cardiff, UK

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1 Introduction

The mass customisation (MC) strategy has been strongly recommended by academics and practitioners over the last three decades. This strategy allows companies to provide customised products at the efficiency of mass production [5] and supports them in facing the increasing demand for variety and the growing competition in the global markets. The practical application of MC is associated with the postponement strategy [50], which has been associated to two main meanings in the literature [12]: (i) the most utilised and traditional applies a "pure standardisation perspective" (i.e. from the make-to-stock, MTS, configuration to MC), aiming at delaying as much production activities as possible, until the customer order arrives, to increase variety; (ii) the less common and more recent applies a "pure customisation perspective" (i.e. from the engineer-to-order, ETO, configuration, to MC), aiming at postponing the product differentiation closer to the time of delivery, to increase efficiency. In both cases, companies applying postponement should define with maximum attention and accuracy what activities must be based on forecast and what on customisation [49]. This makes the postponement concept strongly connected to the customer order decoupling point (CODP) [41], i.e. the point where the customer order occurs, differentiating the activities driven by speculation from the ones driven by customisation [19]. Consequently, the location of the CODP represents a strategic and important choice for companies, but this concept is not completely clear in the literature, and the interpretations are different based on the perspective of the study.

The traditional CODP definition, related to the pure standardisation perspective, takes mainly into account a production dimension (PD) point of view, referring the concept to the main stock point along a continuum of production activities, i.e. manufacturing, assembly and delivery. This view rarely included the engineering phase and distinguished it from the production ones; in the rare cases where this happened, the two dimensions have been analysed as sequential, never overlapped and integrated one with the other. Despite the engineering dimension (ED) did not receive the same attention as the PD in the CODP literature, recent reviews increasingly underlined the importance of its interface with the production one. Dekkers et al. [8] stated that this integration makes the CODP concept suitable to different industries, including the peculiar ETO context. In particular, the two-dimensional CODP (2D-CODP) framework presented by [45] has been underlined in the literature as a good starting point to represent this ED-PD integration [14]. This innovative framework considers the possibility to choose different customisation levels within both the ED and PD and correlates the engineering resources with the operational process [45], anticipating PD constraints in the early phases of the product development [33]. This makes the CODP suitable for different contexts (i.e. both high standardised and high customised) and can help in describing several MC situations not covered by the existing literature. Thus, there is a need to better understand the topic and find the possible interconnections with the MC concept. While the MC and postponement concepts received high attention in the literature, as far as we are aware, there are no systematic literature reviews on the CODP and its correlations with MC (Fig. 1).

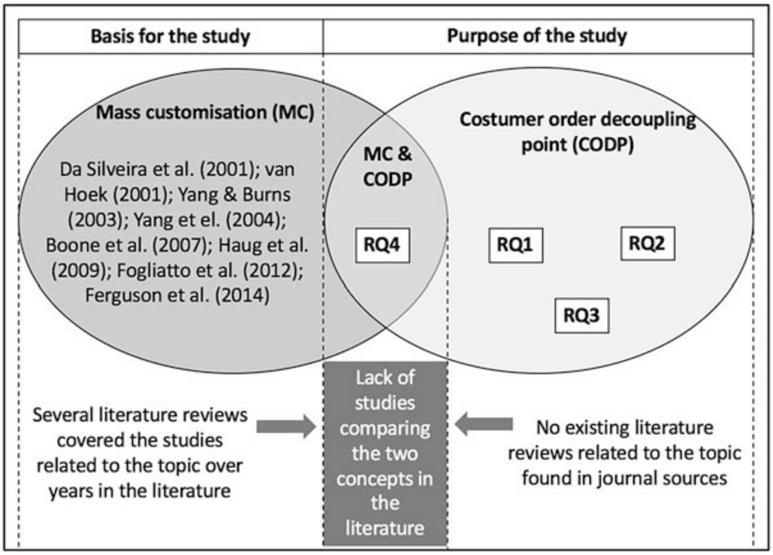

Fig. 1 Purpose of the study

Therefore, this paper presents a literature review on the CODP concept, aiming at structuring the evolution of the CODP theory over years, underlying what has been done and what needs to be done, especially looking at the new two-dimensional perspective. This can help researchers and practitioners to organise the existent knowledge related to the topic, clarify the different views and identify recent trends and uncovered issues. Then, an application of the 2D-CODP concept to the existing MC typologies identifying in the existing literature is shown. This application is useful to clarify that the strong interconnections of the two topics is useful to achieve a broad and comprehensive perspective applicable to the modern industrial contexts. Finally, a structured framework is provided, with new interesting research questions, and opens further research, based on the main gaps found in this study.

The main objective of the study, according to what stated above, is to understand the following points:

- The existent definitions of the CODP and the different possible configurations provided by the literature along the continuum of activities in both production and, when considered, engineering dimension
- The tools to manage the forecast-based and customer order-based activities, to find the optimal balance among them when the CODP is located between pure standardised and pure customised configurations
- The managerial implications of the choice of a certain CODP position, to choose the right level of customisation based on the factors characterising the context where the company operates

- The connections among the 2D-CODP and the MC concept analysed in the literature over years, to understand how the 2D-CODP framework helps in classifying different possible MC configurations

Accordingly, the research aims at answering to the following research questions (RQs), underling the main gaps existent in the literature:

- RQ1: What is the CODP and its possible configurations in the continuum of activities?
- RQ2: How does a company manage the activities upstream to and downstream from the CODP?
- RQ3: Why does a company should shift the CODP backward or forward?
- RQ4: What are the main connections among the 2D-CODP and the MC configurations?

In Fig. 1 the basis for the study and the main purpose, together with the RQs, are shown.

The paper is structured as follows: Section 2 describes in detail the research methodology; the main findings about the CODP literature review are provided in Sect. 3; the existing literature about MC is discussed in Sect. 4 and compared with the results of the CODP literature in Sect. 5; finally, Sect. 6 concludes the paper providing the final discussion and showing the resulting research framework, which opens new research questions for further research.

2 Research Methodology

The literature review was structured in the following steps, according to Cronin et al. [4]: (i) literature searching, (ii) reading and analysis of the literature and (iii) review of the literature.

The main scope of the literature searching (i) was to identify a complete list of valuable studies related to the area of investigation by following a systematic method [3]. The strategy followed in this paper consists in including both empirical and theoretical works, to consider the actual state of the art in terms of conceptualisation, but also the actual practical problems and issues. The time frame of the research, within which the literature was selected and read, starts from the seminal paper to date, since the objective is to analyse and study the evolution of the CODP concept over years. The path followed in this phase is the screening of publications (i.e. scientific journal articles) on two main sources, database of peer-reviewed literature (i.e. Scopus, Web of Science) and the use of a science search engine (i.e. Google Scholar) to support the document searching. The papers are selected based on specific keywords related to the area of investigation, namely, “customer order decoupling point” (OR), “order penetration point” (OR), “order entry point” (OR) and “order fulfilment point”. The keywords chosen are alternative (i.e. Boolean operator “OR”) to obtain as much information as possible related to the topic [4]. This first step has generated a list of 3663 articles from Web of Science and 4988 papers from Scopus. Moreover, a set of filters was applied to the search based on the “subject area”, excluding the areas not related to the industrial engineering, management and economics (e.g. “medicine”, “veterinary”, “neuroscience”, etc.), and the “language”, including only papers written in English language. The choice is to include all the possible source types, i.e. journal articles, conference proceedings and books to have the highest possible overview about the existing knowledge related to the topic. The combination of keywords and the application of a set of filters proposed by the database have generated a list of 283 articles from Web of Science and 430 articles from Scopus.

The second step (ii) consisted in the reading and analysis of the titles and the abstract of the publications, to understand the main contents and to support another inclusion or exclusion process as suggested by [4]. The strategy followed to elect a publication as worthy of further readings, according to [3], is based on the relation of the contents with the main purposes of the study explained in the previous section. Thus, the lists of articles obtained from the previous phase have been crossed and screened, and, in total, 39 papers have been selected to be the starting point for the full-text reading and the review phase.

The review of the literature (iii) structures the knowledge on the topic, defining the relationships among the different studies and understanding how the topic is changed and developed over the years. The selected articles were analysed through a full-text reading and classified trying to answer to the main research questions defined in the previous section. Consequently, they were categorised as “what”, “how” and “why”. The “what” perspective has the main purpose to answer the first research question (RQ1) by defining the interpretation given to the CODP concept and the different configurations of CODPs derived from this interpretation. The “how” perspective is instead related to the second research question (RQ2) by addressing the analysis of the management and control systems related to the location of the CODP. The “why” perspective is related to the studies that look at the CODP concept under a strategic perspective, answering the third research questions (RQ3) by identifying the main reasons and implications related to the CODP shifting. In the following subsections, each of these dimensions is analysed in-depth with respect to the contributions. Finally, the results of the literature review were compared with the existing literature related to MC, widely analysed by several studies. In particular, this analysis started with the comparison with the “what, how and why” of MC introduced by [25]. These perspectives were explained by looking at the several existing reviews on the topic, which already structured effectively the existing literature. This comparison with the MC literature supports the searching for all the possible interconnections among 2D-CODP and MC, answering to the fourth research question (RQ4).

The steps described above are summarised and shown in Fig. 2.

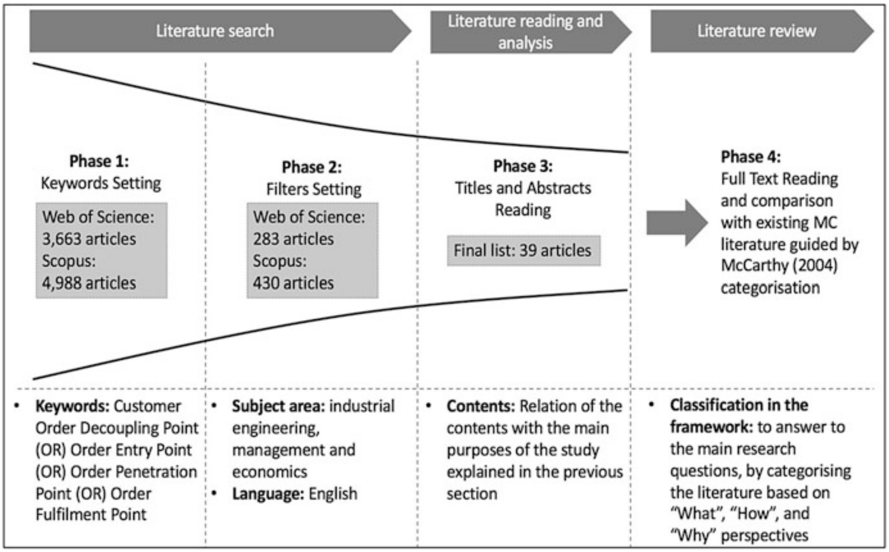

Fig. 2 The literature review methodology

3 The Customer Order Decoupling Point: What, How and Why

3.1 Descriptive Analysis

Table 1 shows the classification of the papers reviewed based on (i) their relationship with the PD and ED; (ii) the specific area to which they gave the main contribution, among the "what", "how" and "why" perspectives; and (iii) the research methodology applied to the study.

Table 1 shows clearly the main research outcomes of the literature review. It is straightforward that most of the studies are related to the PD CODP, while still few studies addressed the ED CODP and its correlation with the PD CODP. Moreover, the analysis points out that each perspective has been studied in the literature with different methodologies. The conceptualisation has been the method mostly used to analyse the "what" and "how" perspectives, while the qualitative methodologies have been mainly used to explore the "how" perspective; finally, the quantitative methods have been principally related to the "why" perspective.

Some articles addressed the ED CODP topic in literature in correlation with the PD CODP, providing new interesting frameworks and suggesting new directions for further researches; but, there is a lack of empirical contribution to the topic. Moreover, no works have been developed in this direction since 2006. But, although this shortage of contributions, the importance of a better understanding related to the ED CODP and its relationship with the PD CODP has been strongly underlined by

Table 1 Literature review classification and results

Genreral methodology	In-depth methodology	References	What		How		Why	
			PD	ED-PD	PD	ED-PD	PD	ED-PD
Conceptual		Sharman (1984)	X				X	
		Wortmann (1992)	X					
		Hoekstra and Romme (1992)	X				X	
		Giesberts and van der Tang (1992)		X				
		Lampel and Mintzberg (1996)			X			
		Porter et al. (1999)		X				
		Olhager (2003)	X				X	
		Rudberg and Wikner (2004)		X		X		X
		Wikner and Rudberg (2005a)		X		X		X
		Hallgren & Olhager (2006)			X			
Qualitative	Multiple case studies	Amaro et al. (1999)		X				
		Mason-Jones et al. (2000b)			X			
		Dekkers (2006)		X		X		X
		van Donk & van Doorne (2016)			X			
	Single case study	van der Vlist et al. (1997)			X			
		Naylor et al. (1999)			X			
		Mason-Jones et al. (2000a)			X			
		Van Donk (2001)					X	
		Wikner and Rudberg (2005b)	X					
		Verdouw et al. (2008)	X					
		Risdiyono and Koomsap (2013)					X	

(continued)

Table 1 (continued)

Genreral methodology	In-depth methodology	References	What		How		Why	
			PD	ED-PD	PD	ED-PD	PD	ED-PD
Quantitative	Optimization model	Sun et al. (2008)					X	
		Fahmy et al. (2015)					X	
		Liu et al. (2015)					X	
		Liu et al. (2016)					X	
	Simulation study	Mason-Jones and Towill (1999)	X					
		Viswanadham and Raghavan (2000)					X	
		Wikner et al. (2007)			X			
		Hedenstierna & Ng (2011)					X	
		Daaboul et al. (2015)						X
		Okongwu et al. (2016)					X	
		Wang & Chen (2016)					X	
	Optimization model and simulation study	Daaboul et al. (2010)					X	
Hybrid methods	Case study and survey	Olhager (2010)			X			
	Case study and focus group	Gosling et al. (2017)		X				

recent works as, for instance, [8, 14]; together with the relevance of the development and in-depth exploration of 2D-CODP frameworks such as the ones developed by [7, 32, 45].

3.2 *What*

The CODP concept is traditionally defined as the point in the material flow where the customer order arrives [13, 19, 35, 48]. Thus, based on the CODP location, it is possible to identify the activities driven by speculations from the activities oriented toward specific customer requirements. In this sense, the CODP represents the main strategic buffer in the materials pipeline where the flow of activities changes from push to pull conditions [16, 18, 22, 24, 29–31, 36, 39, 40, 43].

According to Wortmann [48], there are four main different CODP configurations that can help in classifying the manufacturing systems. The configurations, shown in Fig. 3, are mainly four: (i) ETO, all the activities completely based on customisation; (ii) make-to-order (MTO), production and assembly activities completely based on customer orders, while the engineering activities are based on speculation; (iii) assemble-to-order (ATO), based on a hybrid approach where the engineering and production activities upstream to the CODP are standardised and based on forecast, and the assembly activities downstream from the CODP are customised; and (iv) make-to-stock (MTS), all the activities completely based on speculation.

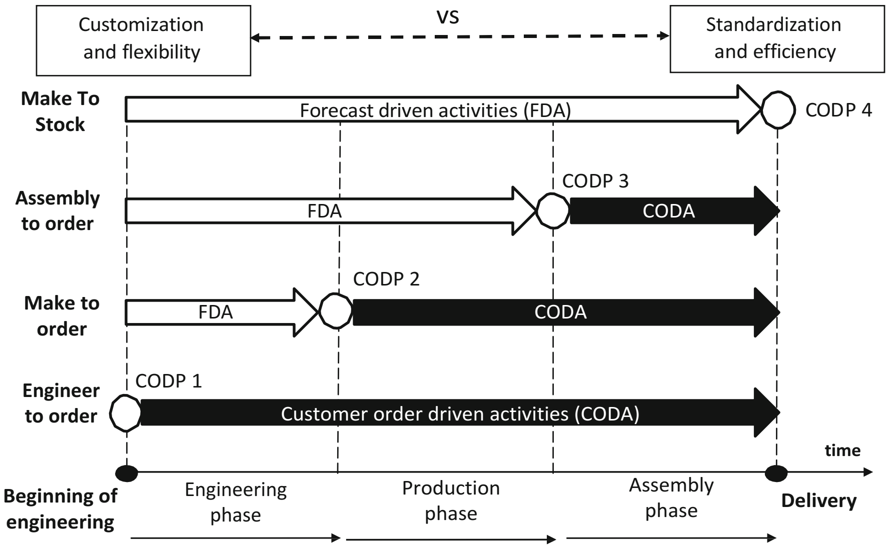

Fig. 3 Manufacturing systems configuration based on different CODP positions [48]

In the literature, not all the researchers agree on the interpretation of the engineering phase and the ETO configuration. Few authors considered the engineering phase as separated from the production phase, maintaining the ETO configuration, for example, [30, 42, 46], while the majority excluded the engineering phase, for example, [13, 16, 18, 23, 27, 36, 39, 40, 47], because the traditional definition of the CODP is related to the PD, making the distinction among ETO and MTO not relevant from a material flow perspective [16].

This definition of the engineering phase was criticised in literature for its very broad meaning first by [1, 31]. They preferred to better detail the different phases related to the ED, taking into account different levels of customisation, distinguishing engineering activities performed to create a completely new design from the ones that adapt an existing design on a specific customer order. In this sense, Porter [31] add different dimensions in the ED, distinguishing design-to-order (DTO), where the product design is completely based on an individual customer order, from ETO, where a standard product range is offered to the customer and modifications are made to request. Furthermore, Wikner and Rudberg [45] and Rudberg and Wikner [32] criticised the traditional sequential approach adopted by CODP literature, which does not differ the PD from the ED. Since the increasing competitive pressure in the markets requires companies to anticipate some production activities acting in combination with the engineering ones, there is a need for a specific framework that considers this possibility to overlap and correlate the ED with the PD. Thus, they specified a new CODP concept related to two dimensions: both PD and ED. They identified six possible CODP configurations: three configurations are related to the PD and consist of the already defined MTO, ATO and MTS, while the other three configurations are related to the ED – (i) ETO_{ED}, product designed from scratch; (ii) adapt-to-order (ATO_{ED}), existing designs adapted based on customer order; and (iii) engineer-to-stock (ETS_{ED}), product design already “in stock”. Dekkers [7] defined a 2D-CODP based on the PD CODP positioned along the traditional material flow and the ED CODP located along the information flow. This second CODP depicts the degree of transformation of product specifications into a detailed product design and production ramp-up. Accordingly, there are four different ED CODP configurations: (i) no engineering activities needed and the production ramp-up is already done; (ii) the design of the product is already defined but the production ramp-up is necessary; (iii) adaptations to the existing product design are needed; and (iv) the product design needs to be completely defined. This new 2D approach makes the CODP suitable to classify not only manufacturing systems but also different types of engineering activities; this is good especially for companies that perform engineering adaptations through the balance of forecasting, based on the past and also the future design needs, and customised activities, based on the specific customer order [32]. Recently, Gosling et al. [15] addressed the empirical study of the CODP concept applied to the engineering activities. They developed a conceptual framework composed by nine potential ED CODP configurations that allow researchers and practitioners to classify the different degrees of customer involvement in the ED. Despite the relevance of this framework, the authors stated that a wider investigation in different

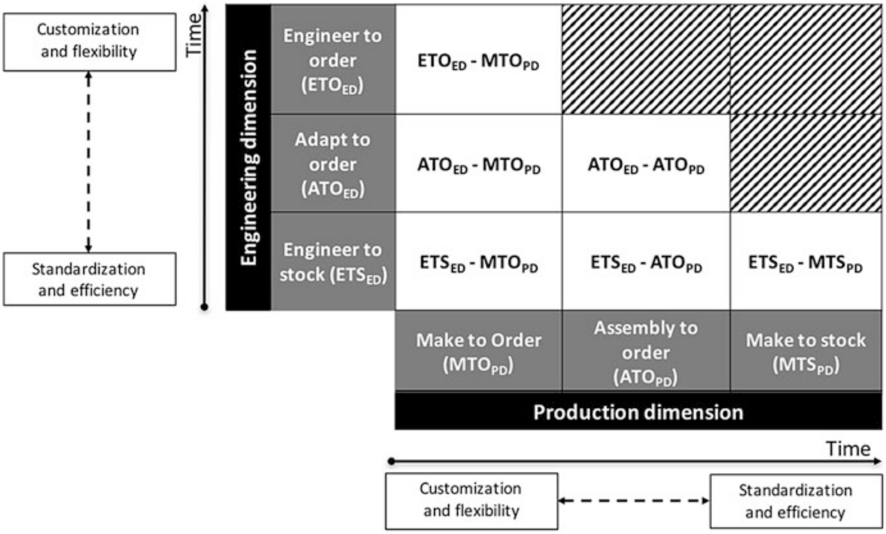

Fig. 4 Configuration based on different 2D-CODP positions [45]

sectors is needed to increase the findings generalisability. Also, the decision-making process that defines the positioning in the different possible CODP configurations needs more in-depth studies.

The 2D-CODP configurations are represented in Fig. 4.

3.3 How

The literature supports the idea that different approaches are needed to manage the activities upstream to and downstream from the CODP [38, 46, 47], since they are led by distinctive drivers, i.e. forecasts vs customer orders [16, 30]. The purpose before the CODP is to control the activities and guarantee maximum internal efficiency, while after the CODP the focus is on satisfying the customer order at the maximum flexibility and at the minimum lead time [7, 42].

Accordingly, the literature suggests two different strategies based on the priorities that the company has in the PD: (i) the lean strategy upstream to the CODP, to reduce all the wastes along the value stream, including time, and (ii) the agile strategy downstream from the CODP, to reach maximum responsiveness for customised and innovative products with unpredictable demand and short life cycle [27]. Thus, the lean approach supports the forecasting-based mechanisms, while the agile approach the fulfilment-related mechanisms [40]. In order to handle the efficiency-flexibility trade-off, the literature suggested to balance the lean and agile strategies by means of the strategic use of the CODP through "leagile" paradigm. This concept was first introduced by [27] that defined the lean and agile approaches as two complementary paradigms instead of unique or sequential along the supply chain. The good combination of these two paradigms by the “leagile” strategy helps to find efficiently a high level of responsiveness [46].

These strategies are related to the PD, but [45] stated that they could be appropriate for the ED where the flexibility-efficiency trade-off also needs to be balanced. [7] stated that this trade-off consists in assuring a good balance among the design customisation and design reutilisation in the ED. But a more in-depth analysis is needed in terms of management and control strategies related to the activities performed before and after the ED CODP [8].

3.4 Why

Traditionally, the CODP positioning is associated with the balance among service level (i.e. companies’ ability to satisfy market requirements assuring delivery reliability in terms of LT, flexibility and stock availability) and costs (i.e. companies’ ability to minimise inventory costs caused by stock holding, stock obsolescence or stock deteriorations) [23, 35, 43]. CODP positioning aims to reach stock reduction and improve flexibility, in accordance with the customer delivery LT [38]. Therefore, CODP positioning is considered a strategic decision that depends on several different drivers and affects lead-time performance [29].

According to Sharman [35], CODP positioning is driven by competitive pressure, leverage within the distribution chain and product cost and complexity. Then, Hoekstra and Romme [19] defined CODP positioning as based on the balance of market requirements and process characteristics. The main driver identified in this sense is the P:D ratio, where P is the production lead time (i.e. the time needed to realise the product along the value-added material flow) and D is the delivery lead time (i.e. the time that a customer is willing to wait). Given this ratio, if P is longer than D, CODP should be shifted downstream to answer effectively to the market requirements. Olhager [29], starting from previous works, defined a “conceptual impact model factor” related to CODP positioning, to support manufacturing companies in choosing the right product delivery strategy based on P:D ratio and the factors affecting it. [29] defined three main factors that affect the positioning: (i) market-related factors, related to all exogenous factors pushing companies in some measures to standardise or customise products (e.g. product demand volatility, product range and product customisation requirements, etc.); (ii) product-related factors, related to the product features (e.g. modular product design, customisation opportunities, etc.); and (iii) production-related factors, related to production process (e.g. production lead time, planning points, etc.). Even if [29] study is an optimal base to identify proper product delivery strategy, it is focused only on PD, and most of the following articles based their studies on this traditional perspective, for example, [16, 18, 20, 28, 30, 36, 42, 44, 46, 47].

Wikner and Rudberg [45] defined the 2D-CODP positioning as based on the relationship among the LT required by the customer and the engineering and production total LT; in addition, they also considered the possibility to overlap ED-PD, considering the sum of engineering and production LTs as affected by a "delta value" (i.e. the slack time between engineering and production). This "delta value" could be zero if they are sequential or negative if they are overlapped [45]. Furthermore, Dekkers [7] stated that upstream shift of the ED CODP improve the flexibility with respect to customer requirements, while the downstream shift of the ED CODP enhances the possibility to reuse existing product designs, diminishing engineering costs and LTs. Recently, Daaboul [6] analysed the simultaneous positioning of the CODP and the PDP (product differentiation point, i.e. the point in which the product design changes from standard to personalised) by performing a simulation study. They stated that these two dimensions should be not considered as exclusive alternatives. Therefore, the PDP and CODP positioning, namely, the variety creation and implementation, should be defined following an integrated decision-making approach that considers the impact on costs, lead times and quality level of the whole supply chain processes. This makes possible to well apply MC, reaching a global value optimisation, not only for the manufacturer but also for all supply chain stakeholders (i.e. customers, suppliers, etc.).

4 The Mass Customisation Strategy: What, How and Why

McCarthy [25] analysed the MC concept from a what, why and how point of view, looking at the existent literature and opening further research in the topic few covered but relevant for this field:

- The what dimension is referred to the definition of MC, traditionally described in the literature as the ability to provide a large number of customers with customised products that satisfy their individual needs [9, 34]. [25] stated that the traditional MC viewpoint excludes companies that realise products in low volumes, referring MC to the ATO_{PD} configuration reached from a MTS_{PD} one. This is a limited perspective; the approaches to the MC can involve different companies' typologies and can be classified in different ways based on the companies' need.
- The how dimension is related to the possible configurations to apply to the manufacturing systems in order to support MC. Among them [25] distinguishes flexibility, postponement, modularity, information technology and CODP positioning. Therefore, in this dimension, the possible CODP configurations (what CODP dimension) and the strategies for the positioning (why CODP dimension) are considered key aspects.
- The why dimension is related to the main reasons for the application of a MC strategy and the consequent implications. In this sense, [25] defined the reasons as mainly based on competitive factors: the capacity to satisfy the market need

for variety, the possibility to handle the shortening of the product life cycles and fast shifting in customer preferences and the opportunity to maintain good performance in the process in terms of costs, quality and delivery, while the implications have been defined as the challenging task of reducing or eliminating the performance trade-off among efficiency and flexibility in the production process.

In the literature, several models conceptualise the MC configurations over years, analysing the what, how and why perspectives. As for the CODP, in the MC literature the broad perspective is still not very considered in the what, how and why dimensions, since the principal way to achieve MC has been related to the traditional postponement, i.e. backward shifting of the CODP: defined as the method to achieve MC, by delaying the activities as latest possible, waiting for the customer order to arrive and specifying the desired product attributes [50], while very little attention received the other interpretation of postponement provided by [12, 17], i.e. the forward shifting of the CODP: method to achieve MC, by moving the differentiation point closer to the market and the time of delivery, increasing the design standardisation and anticipating production activities [12]. In the following, models that consider different possible levels of customisation are analysed.

Mintzberg [26] defined different possible customisation strategies based on when the customer is involved in the process, including the possibility to act in both the design and the production process: (i) design phase, with pure customisation based on specific customer order; (ii) fabrication phase, with tailored customisation based on the modification of basic standard design based on the customer order; (iii) assembly phase, with standard customisation based on different combination of standard components; and (iv) delivery phase, with pure standardisation based completely on forecast. Amaro et al. [1] analysed mass customisation in non-MTS context to understand the new taxonomies needed in these peculiar contexts where customisation is one of the main competitive advantages. He noticed that in the traditional interpretation of MC provided by Pine [34], the only MC view included was the one defined by [26] as standard customisation, while all the other configurations were not considered. Through an empirical investigation, [1] demonstrated that pure customised companies also apply MC strategies, by improving standardisation within their internal engineering and production processes. They affirmed that when the MC concept is applied to non-MTS companies, the reasoning and implications of the application of this approach should include the improving of internal capabilities also in the engineering process. Duray [10] defines the MC as strictly related to the customer involvement in the production cycle and modularity type. This allows to consider different possible MC configurations based on the positioning of the customer involvement in both the engineering and the production processes. The framework developed is a matrix which classifies mass customizers based on the different points of customer involvement proposed by [26] and the different types of modularity provided by Ulrich and Tung [37]. The latter are based on the moment when modularity is applied: in the design or fabrication phase, modularity is capable to modify the components, and the design customisation degree is still high; in the assembly or delivery phase, modularity is capable to add or interchange modules, without modifying them. The mass customizers' typologies identified in this matrix are four: (i) "fabricators", with both customer involvement and modularity at the design/fabrication phase; (ii) "involvers", with the customer involved since the design/fabrication phase, but the modularity at the assembly/delivery phase; (iii) "modularizers", with the customer involved only at the assembly/delivery phase, but the modularity applied at the design/fabrication phase; and (iv) "assemblers", with both customer involvement and modularity at the assembly/delivery phase. Salvador et al. [51] proposed a systemic view of MC, considering product design, marketing, sourcing and manufacturing. They performed an empirical study and identified two different MC typologies: soft and hard. To define different MC typologies, they integrated the modularity type to the supply chain configuration, looking at the customer, the distribution, supply and manufacturing network. The soft MC is defined as the supply chain configuration able to reach high efficiency in terms of economies of scale and scope while providing moderate levels of customisation through component modularity that affect only a small part of the SC. In this configuration customers are served on MTS basis, but the manufacturing and supply processes are able to manage a little level of customisation. The hard MC is defined as the supply chain configuration where customers ask for more customisation but are willing to pay and wait more. In this case, the modularity applied is combinatorial and extensive, involving the entire supply chain that needs a strong interaction among engineering and production activities. In this configuration, the customers are served on MTO/ATO basis, and the manufacturing and supply processes have a strong interaction with the engineering one, able to manage high levels of customisation.

5 Integration of MC and CODP Concepts

All the contributions analysed in the previous section underlined the importance of the inclusion and extension of the ED concept, in correlation with the PD, within the MC, postponement and CODP theories, and the need for more studies related to these field. This PD-ED integration is one point analysed in the literature since the beginning of the MC studies and supported by following studies.

Boone et al. [2] stated that one of the open challenges in the field is to extend MC concept, including the product design process together with the production one, to understand the possible different points until companies can postpone activities with a complete view of the supply chain. Gosling and Naim [14] identified a lack of studies related to the possible strategies to forward shift the CODP from ETO configurations, suggesting the use of modularity to manage the high variety of the context and highlighting the need for more studies about the application of postponement in the design phase. Haug et al. [17] agreed that more efforts should be put in the literature to define MC: on the one hand, by extending the concept to a broader meaning, including the ETO perspective, and, on the other hand, by identifying all the different levels that companies can reach along the continuum of activities from pure customisation to pure standardisation. MacCarthy [21] underlined that there is a continuum of approaches that companies can apply to fulfil the customer requirements for variety and customisation, based on the sector where they operate and changes that affect it over time. These approaches include product design as well as manufacturing aspects in a new integrated perspective that is suitable for different types of industrial sectors. Also, Ferguson et al. [11] underlined the dependency of the successful application of MC to the decision-making in the product development process and provided a product development framework to help in minimising the trade-off among the ideal product design required by the customer and the one available in the company's design solutions.

The importance of the PD-ED integration is straightforward if we try to cross the MC, postponement and CODP frameworks developed over years. In Fig. 5 an attempt of this integration is presented. The pure standardisation view is depicted as a one-dimensional CODP framework, as the one proposed by [19, 48], where the MC configuration is obtained, thanks to the backward shifting from MTS to ATO configuration, as defined by [9, 34]. The pure customisation perspective is depicted as a one-dimensional CODP framework where different customisation configurations are added in the engineering phase, distinguishing DTO and ETO as proposed by [31], and MC is achieved by a forward shifting from pure standardisation to tailored or standard customisation, as proposed by [1, 26]. Finally, the general and broad perspective is depicted as a 2D-CODP, as the one proposed by [45], where the CODP shifting is possible in different directions and from different engineering and production configurations. The different possible MC configurations can be, for example, the ones proposed by [10] and [51] that can be inserted easily and consistently in the 2D-CODP framework.

It is clear from Fig. 5 how the pure standardisation and pure customisation perspectives are limited with respect to the general and broad one, where different strategies can be applied to the shifting from a specific industrial context to different customisation levels. This confirms the importance of further research, conceptual and empirical, to the topic to reach the broad perspective needed in the literature.

6 Discussion and Conclusions

In conclusion, the literature review emphasises important gaps that open interesting spaces for further research. The framework provided in Fig. 6 shows the main results obtained from the CODP and MC literature reviews and the cross analysis of their contents. Everything is explained and discussed below.

About the first research question (RQ1), "What is the CODP and its possible configurations in the continuum of activities?", the existent knowledge agrees on the general conceptualisation of the CODP that is defined as the point at which the customer order arrives and its requirements become the driver of the flow of activities that adds value to the final product/service realised within the

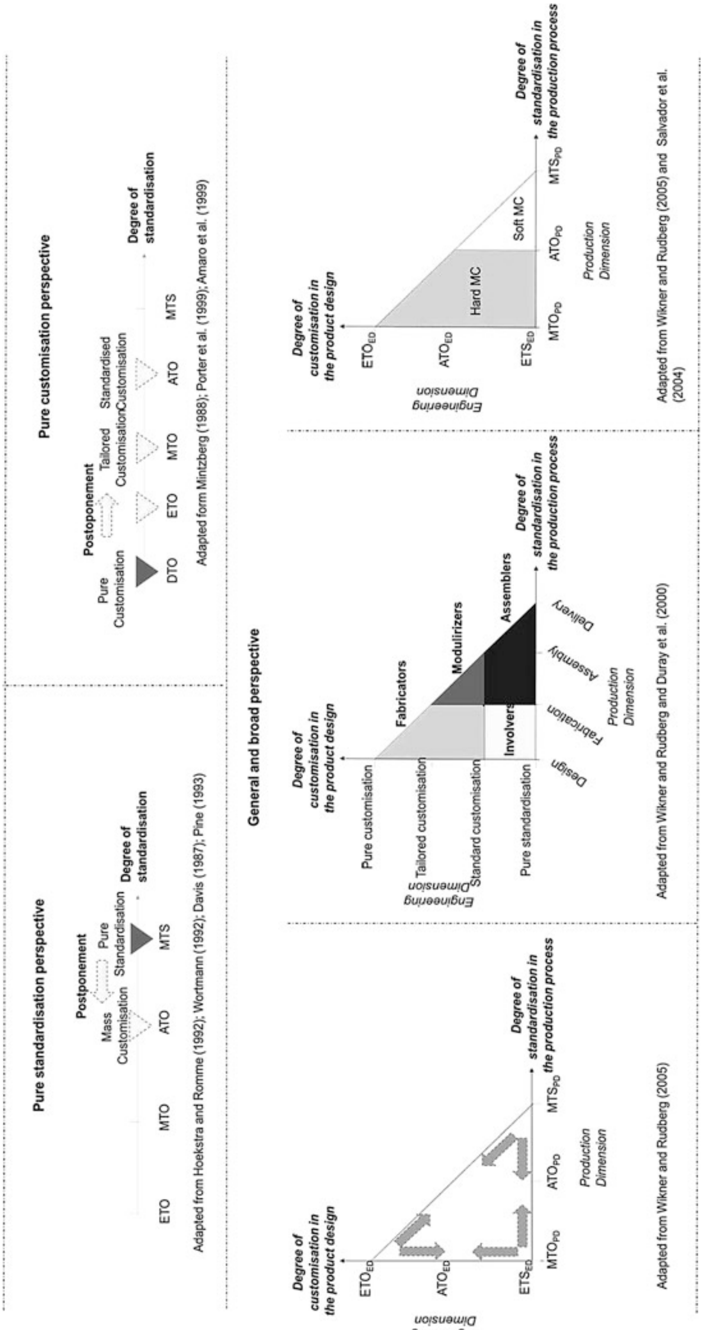

Fig. 5 The mass customisation, postponement and customer order decoupling point concepts from three different perspectives: pure standardisation, pure customisation, general and broad

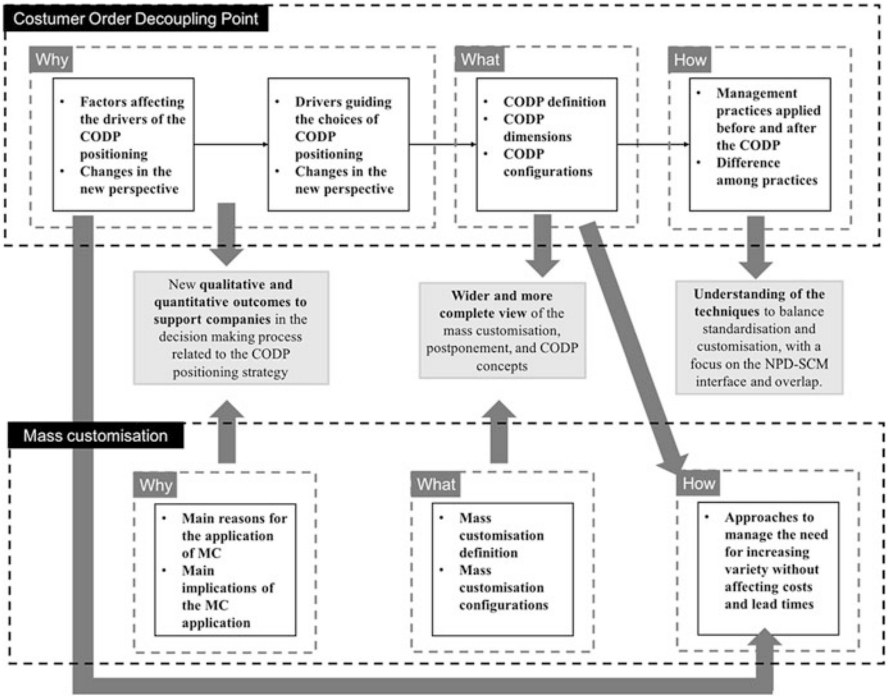

Fig. 6 Main framework developed from the literature

supply chain. Nevertheless, the CODP definition generated also disagreements in the literature over years when related to the ETO sector. The main divergence is related to the definition of what are the possible flows of activities to consider when the product design and development is strongly related to the supply chain management process. This includes the possibility to add dimensions to the CODP concept, looking at multiple flows of activities related to core business processes in the ETO context (i.e. sales, engineering, procurement, production), that are strongly correlated with each other. These flows are often managed concurrently and dynamically by ETO companies [52], with the aim to satisfy a specific customer order. Therefore, the "what" dimension opens a set of possible further research related to the conceptualisation of the CODP that should be addressed, such as:

- Is the CODP physical (stock material point), non-physical (information and/or product specification point) or both?
- How many flows of activities exist in which the CODP can be positioned? Are the activities included in a one-dimensional, two-dimensional or multi-dimensional flow?
- How many meaningful CODP configurations exist in each possible flow?

These research questions need to be investigated principally by empirically testing the different hypotheses present in the literature. A clear and complete definition of the CODP and its configurations, which incorporate perspectives from various industrial sectors, could help to understand the possible levels of customisation existing and the consequent different MC configurations achievable from both high customised and high standardised contexts. In this sense, it could be also interesting to better understand the interconnections among the CODP, MC and postponement concepts both from a theoretical and practical point of view. These interconnections are defined in different ways, from different perspectives and for different aims in the literature, making them not completely straightforward. The effort of classifying and organising the different viewpoints and testing them in real-life contexts could highlight the main gaps and needs in this field and encourage future research to apply a wider and more inclusive viewpoint when analysing these concepts. This answers partially also to RQ4, showing that one of the interconnections among the CODP and MC topics is given by their definitions and configurations including the ED to make the general concept more complete.

Moreover, the possibility to change the traditional view of the CODP unlocks further research also related to the other research questions. Indeed, as underlined in the literature review, the answer to the questions RQ2 *How does a company manage the activities upstream to and downstream from the CODP*? and RQ3 *Why does a company should shift the CODP backward or forward*? are strongly investigated in the material, one-dimensional CODP. But what happens if the CODP is non-material and requires more configurations and/or dimensions?

Thus, here interesting new questions are provided. About the how dimension:

- What are the management practices applied before and after this new CODP conceptualisation?
- Do the practices still difference before and after the CODP in a new CODP conceptualisation?

The techniques studied in the literature to manage standardised and customised activities are several, but often not interrelated one with the other. This correlation is important to make possible the understanding of the actual supply chain configurations that characterise the global and modern markets: where the standardisation and customisation must be necessary balanced. The traditional techniques should be studied in their application before and after the CODP, to understand how to reduce or, when possible, to eliminate the trade-off among productivity and flexibility, to obtain a global optimisation (i.e. to stay competitive by satisfying the market requirements with the desired products while reaching good performance in the internal processes needed to realise them). Especially, the techniques that allow the product development and supply chain management processes to be accomplished in combination and overlapping need to be more studied and stressed in the following studies related to the topic.

About the "why" dimension:

- What are the drivers guiding the choice of the new CODP positioning? Is still the P:D ratio the only driver for the positioning?

- What are the factors affecting the drivers guiding the choice of the new CODP positioning? Are still only market, product and production related?

Further research is needed to understand the companies' behaviour and the best practices to guide the decision-making process in different industrial sectors and customisation levels. This should be done by empirically analysing different industrial contexts, with a focus on the high customised ones, less analysed in the past works. This effort could help both academics and practitioners. On the one hand, the definition of new drivers and factors affecting the CODP positioning from a larger perspective could support new quantitative studies, which well addressed this subject, to measure the effects of different positioning on the product development and supply chain performance and to optimise the CODP location based on different drivers and factors identified. On the other hand, the outcome of qualitative and quantitative studies could support practitioners in choosing the best strategy to apply in a continuum of different possibilities, based on the characteristics of the context where they operate.

Finally, the why and how dimensions of the MC analysed in the previous chapter complete the answer to the last research question (RQ4). The why dimension, i.e. the MC reasons and implications, enriches the new qualitative and quantitative outcomes to support the CODP positioning, while the how perspective of MC, i.e. the strategies to implement MC, can be better defined, thanks to the in-depth analysis of the what and why perspective in the CODP framework. Therefore, further analysis in the MC theory and practice, including the 2D-CODP view, can support the study and application of MC in a broader perspective, in different industrial realities, from different starting points.

In conclusion, the contribution of the academic world in this field is highly required and essential to influence and guide all the industrial realities, and their entire supply chains, to stay competitive in the actual global markets. The main scope is to support them in (i) finding the most suitable configuration to balance the benefits of customisation with the ones provided by standardisation, (ii) managing the customised and standardised activities by acting on the engineering and production interfaces and (iii) achieving, according to the internal and external characteristics affecting their contexts, the most suitable 2D-CODP configuration and MC strategy to improve global performance.

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