Insights from the empirical applications of the customer order decoupling point

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Abstract
Knowledge relating to the role of the customer order decoupling point (CODP) in Engineer-to-Order (ETO) supply chain management is available in the literature but fragmented and not synthesized in a coherent body of knowledge. This paper proposes a systematic review of the recent empirical studies developed in the ETO-CODP literature, to understand the existing contributions to the ETO definition (*what*), managerial approaches (*how*) and managerial implications (*why*) based on the different methodologies and the nature of the ETO sectors analysed. The outcome of the study is the identification of current gaps and proposition of existing opportunities for further empirical research.

Keywords: Decoupling point, Engineer-to-order, Supply chain management, Empirical research, Literature review

Introduction
The customer order decoupling point (CODP) was described by the seminal studies (Sharman, 1984; Hoekstra and Romme, 1992) as a strategic point, which defines the moment in the value stream when the product is assigned to a specific customer order. The theoretical foundation of the CODP literature is the contingency theory, which is based on the idea that there is not a best way to manage different instances, and distinctive solutions can be found based on the specific environment where an organization operates (Olhager and Prajogo, 2012). In this sense, the literature underlines the importance to fit the manufacturing and supply chain operations to the position of the CODP, by managing them based on the customer order fulfilment strategy chosen.

The traditional literature relates the different nature of the organizations, based on the CODP positioning, to four main configurations: (i) make-to-stock (MTS), i.e. design and production activities completely based on speculation, focused on demand forecasting, marketing, distribution and stock control; (ii) assembly-to-order (ATO), i.e. assembly activities performed to order to increase innovation and effectively answer to the mix of orders; (iii) make-to-order (MTO), i.e. production activities performed to order to assure the customisation of the production processes and focus on the manufacturing engineering improvement; (iv) engineer-to-order (ETO), i.e. design and production activities performed to order, to assure the customisation of the product specification and focus on the engineering activities. The traditional CODP concept and most of the following studies were addressed to the MTO, ATO and MTS, without focusing on the ETO concept. Gosling & Naim (2009), in their review of the ETO supply chain management literature, identified confusion around this topic and recognised the innovative CODP frameworks developed over years as helpful to overcome this confusion. The decoupling concept was, indeed, related not only to the material but also to the information flows along the value chain (Mason-Jones and Towill, 1999), and this triggered a shift from a decoupling point concept to a decoupling zone included between the point where the information is 100% uncertain and the point where it becomes 100% certain (Wikner and Rudberg, 2005b), and from a one-dimensional framework to a two-dimensional one, i.e. the decoupling of information and material flows in the engineering and production dimensions (Amaro et al., 1999; Wikner and Rudberg, 2005a). This evolution of the decoupling concept brought a more comprehensive view and made possible to analyse the impact of customer demand on product design. The management of the order entry points along the engineering activities supports the re-use of existing designs and the application of modularity to reduce lead time and costs (Dekkers, 2006).

Gosling & Naim (2009) defined these studies a good starting point to better understand the ETO concept. Further research was developed since 2009 addressing the topic. However, the outcomes of these studies highly vary one from the other and the knowledge available is fragmented. This brings complexity in the results generalization and the practical applications of the theories, and provides unsolved issues to be clarified. There is a need to synthesize into a holistic, coherent body of knowledge the managerial approaches and implications related to the different strategies that can be applied in the ETO sectors. To the best of the authors' knowledge, no systematic reviews were developed from 2009 to date related to the CODP and its role for the ETO supply chain management. This study aims at filling this gap by systematically analysing and organising the knowledge developed in the last years with a focus on the empirical studies. The research purpose is related to: (i) understand the state-of-the-art of the CODP in the ETO supply chain management and the main empirical contributions existing in the literature; (ii) detect the main gaps and the areas opened for further research to provide insights and contributions to the ETO supply chain management from a theoretical and practical point of view. In particular, the main research purpose is to answer to the following research questions: (RQ1) *"What" are the properties of companies belonging to each ETO CODP configuration?*; (RQ2) *"How" do ETO organizations manage the activities based on the CODP configuration applied?*; (RQ3) *"Why" do ETO organizations shift the CODP and redesign their systems?*.

Methodology

The methodology proposed in this paper is a systematic review of the empirical studies developed in the CODP literature related to the ETO supply chain management. Following the steps suggested by Tranfield et al. (2003), once defined the main research purpose, the review process starts with the selection of the main studies related to the topic. The choice is to select papers published in international journals and available in database of peer-reviewed literature such as: “Scopus” and “Web of Science”. The keywords used in the research are: “engineer to order” OR “one of a kind” OR “build to order” OR “engineering decoupling point” OR “engineering penetration point” OR “engineering entry point” OR “information decoupling point” OR “information penetration point” OR “information penetration point”. Almost 200 thousand papers have been identified after the keywords search. Then, the criteria followed to select the appropriate literature are based on database filters: (i) Research areas: management, business and economics; manufacturing and industrial engineering; (ii) Language: English; (iii) Source: journal article; (iv) Years: from 2009 to 2018. The filters reduced the number of the papers to 1 thousand. Finally, to select the papers worth for full text reading, titles and abstracts has been read and, based on the main purpose defined in the introduction, the papers have been included or excluded. In total, 32 papers have been selected. The selected papers have been published in different journals, and the most significant ones (in terms of number of papers published over years) are International Journal of Production Research, International Journal of Production Economics, Production Planning & Control, Journal Of Manufacturing Technology Management, International Journal of Operation and Production Management, and Construction Management And Economics. From 2009 to 2018 they were published with an increasing trend, shown in Figure 1, that confirms the growing interest in this topic from the recent literature. Once the first statistics were analysed, the researchers focused the study on the review of the selected papers in order to classify and categorise the existing literature and identify the new trends, with the aim to answer to the research questions defined at the beginning of the study (“What”, “How”, and “Why” dimensions).

What dimension

The object of interest of the “What” dimension is related to the understanding of the ETO meaning and its evolution over years. Gosling & Naim (2009) recognised the existence of different ETO configurations and defined the concept as related to the level of customer involvement in the design and production flows. In this sense, they recommend further research to better understand the different ETO types. Accordingly, the recent interest in the literature has been addressed to the analysis of the nature of customisation and the characteristics of the specific sectors analysed (i.e. the additional insights that the properties of the different cases add to understanding the ETO environment). In particular, Willner et al. (2016) explored the archetypes of ETO to support companies in defining the appropriate level of standardisation and automation based on the engineering efforts and production volumes required for their products. They studied different sectors (machinery, elevators, aircrafts, etc.) in different countries (Switzerland, Italy, Austria, China) through a multiple case study research and identified four different possible ETO configurations: complex ETO with low standardisation and automation, which requires high engineering efforts, low production volumes and very long lead times highly affected by the engineering activities; basic ETO with medium standardisation and automation, mainly based on the modification of existing designs that affects the lead time depending on the amount of customisation required, i.e. medium to long lead times; non-repeatable ETO with high standardisation and automation, managed through mass customisation with high repetitiveness of processes and engineering modifications seen as exceptions; non-competitive ETO, defined as unsuccessful archetype, very rare and difficult to find in empirical situations and not very convenient to keep in the long term. Gosling et al. (2017) deeply analysed the level of customer engagement in the engineering process to add insights to the ETO concept and make it more suitable to the practical application. They performed a focus group of 7 senior practitioners and multiple case studies research in one specific industry, the UK civil and structural engineering, analysing 8 different projects. The empirical study allows the researchers to classify the different cases based on nine subclasses of engineering activities performed based on customer order. The subclasses can be classified in three different categories based on the level of customer engagement in the engineering: involvement in the research activities (science, math and engineering), little addressed in the literature but very important for companies that need to perform them based on a specific customer order; involvement in the development of codes and standard (develop codes, integrate codes and new design); involvement in modification of existing designs (adapted, finalized and complete design), which is the most addressed area in the literature. The need for further empirical investigation in this field was underlined by these studies, both in terms of addressing larger populations and different sectors, and applying quantitative analyses.

How dimension

Lean and agile

The managerial approaches before and after the CODP were defined as different by Naylor et al. (1999), which defined the lean paradigm suitable to be applied upstream of the CODP, where the demand is smooth and regular, and the product flows are standard; while, the agile paradigm is suitable to be applied downstream from the CODP, where the demand is variable and product variety high. Gosling & Naim (2009) identified that there are disagreement about the application of lean and agile to the ETO sector. Traditionally, the agile technique is considered the one to be applied in the ETO context, but recent studies addressed the topic to better understand the level of applicability of lean techniques in the real-life organizations. In the last years, Lu et al. (2011) analysed the application of a lean and agile models through a multiple case studies research in two Swedish homebuilders and shown that the combination of the two techniques is not applied by the companies interviewed. Nevertheless, a simulation study was then developed to show how to combine them and achieve improvements in terms of time and cost reduction. Pham and Thomas (2011) developed a framework for the implementation of sustainable manufacturing operations within organisations through the application of lean and agile in combination with other innovative management concepts. This combination helps in reducing uncertainty but maintain the adaptability to new products, technologies and markets. It is based on a Fit Manufacturing Framework applied and tested by means of an action research in six UK companies belonging to different sectors such as aerospace, precise engineering, musical instrument, etc.

About the implementation of lean in ETO context, Veldam & Klingenberg (2009) demonstrated the applicability of a Capability Maturity Model Integrated a ETO case study through the analysis of the main challenges and the identification of guidelines to implement lean production to this kind of organizations. Then, a specific lean engineer-to-order production system has been analysed by Matt (2014) validated an adapted value stream map approach for ETO contexts through an empirical case study in an Italian steel construction company. Recently, Birkie and Trucco (2016) analysed the impact of uncertainty and complexity in the application of lean approaches through an in-depth case study in two capital goods manufacturing companies, one located in Italy and one in US. They underlined that the interest of ETO companies in implementing lean practices is well justified. In this sense. the impact of the implementation of lean practice in ETO contexts has been analysed recently by Birkie et al. (2017). They demonstrated the possibility of performance substance thanks to lean practice application and underlined the difference with respect to lean mass production applications. Finally, Seth et al. (2017) analysed a case study in an Indian industrial power transformer making company and demonstrated that the VSM application remain the same for simple and complex environments and provided guidelines to facilitate lean in ETO. In general, the lack of quantitative analysis was underlined in this field. About the implementation of flexibility techniques in the ETO context, Engelhardt-Nowitzki (2012) and Gosling et al. (2013) proposed different flexibility frameworks for ETO companies through multiple case studies research in different sectors. These framework help companies in enhance and manage flexibility in value chains affected by high uncertainty.

Supply chain coordination
Other important managerial approaches addressed in the literature and tested in terms of applicability in ETO context are related the supply chain integration. Gosling et al. (2015) analysed for the first time the application of the FORRIDGE principles to non-MTS sectors, by studying them in different case studies in the construction industry. They demonstrated the applicability of the principles and the need to adapt them to the ETO context with additional insights (e.g. the design for X was identified as crucial for companies involving new designs for each customer). In the shipbuilding industry, Mello et al. (2015a) analysed the role of coordination in avoiding project delays and Mello et al. (2015b) analysed the factors affecting coordination. While, the role of each individual company in the coordination of ETO supply chain was analysed by Mello et al. (2017) providing seven principles based on findings in multiple case studies research in the shipbuilding industry. Li et al. (2014) proposed a survey addressing different sectors to compare the effects of collaboration in different customisation scenarios, showing that it affects the market performance of build-to-order companies.

Design and production planning
Moreover, the planning and control activities performed in ETO contexts based on the requirement of individual customers is an important topic addressed in the literature both from a quantitative (Hong et al., 2010) and a qualitative (Adrodegari et al., 2015) viewpoint. Hong et al. (2010) proposed a co-evolutionary genetic programming and numerical optimisation to concurrently managed the product design and process planning in one-of-a-kind systems. The effectiveness of the results was shown through the application in a real industrial case study of a windows making company. Grabenstetter & Usher (2013) analysed through a multiple case study research in various ETO industries. The study focused on the identification of factors affecting complexity in the ETO environment to understand how to improve the forecasting of engineering flow times and due date estimation. In the same industries, Grabenstetter & Usher (2014; 2015) proposed quantitative models based on an algorithm to develop due dates and sequence jobs in ETO environments. Adrodegari et al. (2015) developed a tailored framework to show how to perform production planning and control in the ETO contexts through the analysis of 21 case studies in the Italian machinery-building industry. They divided the activities in "engineering and plan" (where the first contact with the customer is managed and the engineering activities, together with the process plan start) and "execution and control" (where the final version of the product is realised based on customer requirements and production activities are executed). The need for the implementation of new managerial approaches addressing the ETO context were underlined in this area.

New product development
New product development improvement was addressed by Kumar & Wellbrock (2009) in a case study that analysed the ETO new product development and implemented an improvement in the process that reduced the total lead time of the project from 40 to 24 days and increase other performance such as the on-time delivery and the product yield.

In doing this, they underlined the importance of the application of methods to better manage the front-end and address the customers' design concerns early in the engineering process. Also, the communication and the co-location of people involved in the process is considered as very relevant. Other authors underlined the relevance of the engineering design and the management of methods to improve the product structure. Jansson et al. (2014) and Johnsson (2013) analysed the product platforms in the construction industries and their impact on the ETO companies. The first underlined the importance of design support methods in daily engineering work when using them, while the second identified different platforms and shown their benefits for ETO companies. Additional studies were provided in the catalysts manufacturing industry by Shafiee et al. (2014) that defined a framework for scoping, defining and controlling product configuration project; and later, by Kristjansdottir et al. (2017), which proposed different applications of Product Configuration Systems. Also, the impact of design modularity on ETO supply chains was study by Pero et al. (2015) within the construction and shipbuilding industries, demonstrating the positive impact of modularity on supply chain performance.

ETO Mass customization

Haug et al. (2009) analysed the literature related to the transition from ETO to MC and underlined the presence of confusion around this topic due to the lack of a broader view that includes interpretations different from the traditional ones analysed in the MTS literature. In particular the absence of a discussions related to challenges and benefits from the MC application in ETO contexts was underlined. In this sense, Dean et al. (2009) analysed an information system that could support the application of MC in one-of-a-kind systems. This information system includes a product data modelling that supports the knowledge to structure the product database and identify product families. The system has been tested in a windows and doors manufacturing company, showing interesting applicability of MC in ETO contexts with the support of this technology. Also, a recent contribution from Sandrin et al. (2018) provided guidance to firms that aim to transition from custom manufacturing (ETO) to full MC by means of a survey research developed in various ETO industries. The need for further research is underlined by this study in order to improve the knowledge and address different cases.

Why dimension

An important study related to the managerial implications of the traditional CODP positioning was developed by Olhager (2003). He underlined the strategic issues, reasons and negative effects of shifting the CODP backwards or forwards. The market, product and processes characteristics together with the competitive priorities of the company has been identified as main drivers for the positioning. Recent studies enriched this literature stream, identifying new determinants for the positioning in high customised configurations. Millner (2016), in its study related to the ETO archetypes, addressed also this issue underling that both external and internal factors may have an impact in terms of changes in the customer or internal technical requirements that increase the engineering complexity and trigger the strategic shifting to different positioning. Also, Gosling et al. (2017) identified reasons for the shifting of the CODP along the engineering dimension and related them mainly to the abilities and capabilities of the engineering department and the whole supply chain in answering to the customers in terms of delivery lead times and uniqueness of the solution. Finally, another recent contribution was provided by the Schoenwitz et al. (2017) study. In this paper, the alignment between the CODP configurations (at components level) and the customer preferences in terms of customisation requirements are the most important aspects to be considered. Companies must redesign their systems, develop new products or components and/or address new markets in order to achieve this alignment when it is missing. The empirical analysis was related to a German housebuilder and focus group and interviews were applied as research method. The findings help in understanding how to configure and manage the product structure based on the customer preference measure for categories and components.

Discussion and Conclusion

In this paper the main outcomes of the literature review related to the role of the CODP in ETO supply chain management are provided and structured based on the main research questions of the paper. Table 2 provides a final classification of all the 32 papers selected and analysed based on a systematic selection of the literature contributions from 2009, year of publication of the ETO supply chain management review developed by Gosling & Naim (2009), to date.

Table 1 – Literature review outcomes

Methodology	Reference	Sector/s analysed	Theme	Research area/s
Multiple case studies	Adrodegari et al. (2015)	Machinery industry	How	Design and production planning in ETO contexts (4)
	Birkie & Trucco (2016)	Machinery and industrial equipment industry	How	Implementation of lean in ETO contexts (2b)
	Birkie et al. (2017)	Hydraulic power units, flow control devices	How	Implementation of lean in ETO contexts (2b)
	Engelhardt-Nowitzki (2012)	Various (Agricultural machines and OEM)	How	Implementation of flexibility in ETO contexts (2c)
	Gosling et al. (2013)	Construction	How	Implementation of flexibility in ETO contexts (2c)
	Gosling et al. (2015)	Construction	How	Supply chain integration
	Grabenstetter & Usher (2013)	Various (motor control center, busway, etc)	How	Design and production planning in ETO contexts (4)
	Jansson et al. (2014)	Construction	How	New product development in ETO contexts (5)
	Johnsson (2013)	Construction	How	New product development in ETO contexts (5)
	Mello et al. (2015b)	Shipbuilding	How	Supply chain coordination in ETO contexts (3)
	Mello et al. (2017)	Shipbuilding	How	Supply chain coordination in ETO contexts (3)
	Pero et al. (2015)	Construction and Shipbuilding	How	New product development in ETO contexts (5)
	van Donk & van Doorne (2016)	Metal processing industry	How	Supply chain coordination in ETO contexts (3)
	Willner et al. (2016)	Various (machinery, elevators, aircrafts, etc)	What/Why	ETO archetypes and determinants for the positioning (1)
Single case study	Dean et al. (2009)	Construction	How	Implementation of mass customization in ETO contexts (6)
	Matt (2014)	Steel Construction	How	Implementation of lean in ETO contexts (2b)
	Mello et al. (2015a)	Shipbuilding	How	Supply chain coordination in ETO contexts (3)
	Seth et al. (2017)	Industrial power transformer	How	Implementation of lean in ETO contexts (2b)
	Shafiee et al. (2014)	Catalysts	How	New product development in ETO contexts (5)
	Kristjansdottir et al. (2017)	Catalysts	How	New product development in ETO contexts (5)
	Kumar & Wellbrock (2009)	Flexible printed circuits	How	New product development in ETO contexts (5)
	Veldam & Klingenberg (2009)	Gas production	How	Implementation of lean in ETO contexts (2b)

Action research	Haug et al. (2013)	Various (heating, ventilation, etc)	How	New product development in ETO contexts (5)
	Pham & Thomas (2011)	Various (aerospace, precise engineering, etc)	How	Implementation of lean and agile in ETO contexts (2a)
Focus group, case study	Gosling et al. (2017)	Construction	What/Why	ETO archetypes and determinants for the positioning (1)
	Schoenwitz et al. (2017)	Construction	Why	ETO archetypes and determinants for the positioning (1)
Simulation, case study	Lu et al. (2011)	Construction	How	Implementation of lean and agile in ETO contexts (2)
Survey research	Sandrin et al. (2018)	Various (machinery, electronics, etc)	How	Implementation of mass customization in ETO contexts (6)
	Li et al. (2014)	Various (construction, machinery, etc)	How	Supply chain coordination in ETO contexts (3)
Mathematical models	Grabenstetter & Usher (2015)	Various (motor control center, busway, etc)	How	Design and production planning in ETO contexts (4)
	Grabenstetter & Usher (2014)	Various (motor control center, busway, etc)	How	Design and production planning in ETO contexts (4)
	Hong et al. (2010)	Construction	How	Design and production planning in ETO contexts (4)

The supremacy of case study research as main research method, already underlined by Gosling & Naim (2009), is confirmed even in the recent literature, but there is an interesting increasing trend in the application of empirical studies and in the utilisation of primary data. Also, the selection of different methodologies for the research started: focus group, action research, survey research, mathematical and simulation models. About these methods, despite their applications are increasing over years, the literature is still underling the need for further investigation and application to real case studies.

About the sectors analysed, they were different, the mostly addressing ETO sectors such as construction, machinery and capital goods, shipbuilding, and other specific ETO sectors such as industrial power transformers, flexible printed circuits, etc. The studies addressed their analyses mostly to one sector and, in some cases, more than one sector, but all focused on ETO contexts. Finally, they were performed in different countries (UK, Sweden, Italy, Switzerland, China etc.), in some cases simultaneously, testing different cultural and economic environments.

The main contribution to the different themes analysed ("What", "How" and "Why") has been analysed. The results show a great contribution to the "how" dimension, that adds insights to the existing basis of the ETO-CODP literature and opens interesting further research. About the what and why dimensions, very recent studies explore new outcomes to improve the understanding of the different ETO types and their managerial implications. Nevertheless, the need for further research is high, both from a qualitative and quantitative viewpoint. Other sectors and larger populations must be addressed, and quantitative studies should start to be developed.

Finally, the issues to be addressed in the ETO field, opened by the literature in the last ten years can be distinguished in very different research areas: (1) ETO archetypes and determinants for the positioning; (2a) Implementation of lean and agile in ETO contexts; (2b) implementation of lean in the ETO context; (2c) implementation of flexibility in the ETO context; (3) Supply chain coordination in ETO contexts; (4) Design and production planning in ETO contexts; (5) New product development improvement in ETO contexts; (6) Implementation of mass customization in ETO contexts.

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