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Engineer-to-Order Challenges and Issues: A Systematic Literature Review of the manufacturing industry

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Abstract

Companies in engineer–to–order (ETO) manufacturing environments that seek efficiency gains through adopting a mass customisation strategy meet significant challenges. The implementation of the mass customisation (MC) strongly focuses on transitioning from mass production. The purpose of this study is to identify current areas of concern and operational challenges when adopting mass customisation principles in ETO companies. A Systematic Literature Review (SLR) was carried to evaluate the challenges the Portuguese Industry faces in the moulding companies' sectors and how they are improving their ability to meet deadlines. The study will look at ways of boosting customer satisfaction by providing unique products at a relatively low cost. The study exposed issues of MC in ETO companies in general, it is critical to achieving more efficient use of resources, workflow, and innovative management methods and approaches to deal with the variability and complexity of this manufacturing system. The competitive pressure to achieve better efficiency and effectiveness in this type of organisation requires constantly searching for new concepts and tools that can be developed and applied. Furthermore, this paper explores the ETO companies' significant difficulties and the technical and scientific solutions used and proposed as its significant contribution, as well as a proposal for future research and development to increase ETO companies' resilience and performance level in managing their value chain and executing operations in response to customer requirements.

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1. Introduction

1.1. Background

The engineer-to-order (ETO) companies are typically dedicated to manufacturing complex products with a relevant engineering component and high-added value products. These companies, particularly in Portugal, are generally small and medium-sized, playing a significant role in specific sectors and regions, operating mainly in international markets. The economic development of a region and the need to ensure the company's competitiveness in an increasingly global economy is significant. Those companies supply many industrial sectors as diverse as the automotive, aeronautical, and pharmaceutical/medical device industries. Their business model will base on the value they provide to their clients in their ability to design, develop and manufacture products to order [1]. The moulding industry is an example of a sector where this type of company is common. Production planning and shop floor management are two activities whose difficulty is much related to the product and process diversity that increases system variability and complexity. Responding adequately to customers' expectations, an enormous demand is required in these very competitive sectors to execute many activities. So, the effectiveness of the shop floor planning and decisions making is common for this type of company, as they must fulfil within increasing shorter delivery times defined by the market or clients that are also requesting increasing quality and lower costs. The ETO companies often deal with a workflow in which product design, bill of material (BOM) details, and the required drawings and manufacturing work instructions for each order must be quickly generated and used to meet the tailored customer's specifications.

1.2. Scope and Outline

The variety of work to be developed in ETO companies, the complexity of customised products and the underlying uncertainties of the markets require planning and decision-making combined with other core processes, such as bidding and procurement for improved results, throughout their value chain. Therefore, this work is motivated by the need (a) to support ETO companies to be more efficient and effective in the performance of their activities, incrementing their role or relevance in a particular type of industrial sector and the economy; (b) to provide new methods, methodologies, techniques or tools to ETO companies to increment their competitiveness; and (c) to minimise the difficulties inherent to the ETO business, i.e., improve their ability to deal with overall value chain variability and complexity. The Systematic Literature Review (SLR) performed aims to identify the main challenges and issues related to the ETO companies, as well as methods and approaches presented in the scientific literature to resolve or mitigate these issues in the value chain of this type of company and identify potential current drawbacks. So, the search for scientific literature on the topic in question is intended to gain knowledge about the several viewpoints and to interpret the study's theories and models in a holistic approach. This paper is organised as follows: Section 2 provides a review methodology. Section 3 discusses the findings. Finally, section 4 presents the major study conclusions and identifies future works.

2. Methodology

This paper is a systematic literature review on ETO companies' difficulties and proposed technical and scientific solutions. Systematic literature reviews differ from Narrative reviews in the way they seek to answer a particular research question, i.e., by using a planned and systematic method to identify, select and critically appraise the studies included in the literature review [2]. The SLR allows access to different authors' contributions and analyses and synthesises the results of relevant literature. This way, we understand the breadth and depth of the existing body of work identify gaps to explore, and allow conclusions on what is known and not known [3]. The SLR methodology performs a systematic literature search according to the PRISMA [5] guidance approach. Specific eligibility criteria included the following: (a) papers discussing ETO problems; (b) process planning; (c) manufacturing articles related; (d) production planning and control; (e) articles published in English. The articles that did not meet the previous criteria were excluded; (g) articles about building and ships and (h) systematics review articles were also disqualified. Studies were exhaustively identified by searching digital databases of articles published from January 2017 to April 2022. The papers of this review were searched via the Web of Science and Scopus database. The search terms were as follows: ‘engineer* to order’ AND ‘variab*’ OR ‘uncertaint*’ OR ‘complex*’ AND ‘produc* control’ OR ‘plan*’ OR ‘schedul*’ OR ‘produc* process’ OR ‘workflow*’ OR ‘shop-floor*’ OR ‘digital*’ OR ‘problem*’ OR ‘issue*’ OR ‘constraint*’ OR ‘unefficien*’ NOT ‘ship*’ OR ‘building*’.

The flow of citation through the systematic review process is depicted in figure 1. The study search yielded a total of 140 potentially relevant publications. This assessment presented the basis for selecting 24 papers, as shown in Figure 1. One hundred and eight publications were screened for inclusion in the study after (n=32) were excluded. Further, six more were included, prefacing 24 potentially relevant publications. Sixty-two articles did not meet the criteria and were therefore rejected at the title and abstract level. Finally, 46 potentially relevant citations were obtained, and only 18 articles were relevant. Further, six more were included, prefacing 24 potentially relevant publications. This assessment presented the basis for selecting 24 papers, as shown in Figure 1. While the study assessed the shortlisted studies in light of the identified inclusion/exclusion criteria, we also feel that the 24 shortlisted papers represent a robust number for analysis. Previous studies in different domains have used similar sample sizes, such as 19 papers in nursing [4], 23 papers in learning management [5] and 23 papers in project management [6]. Hence, our sample size of 24 papers is also justified.

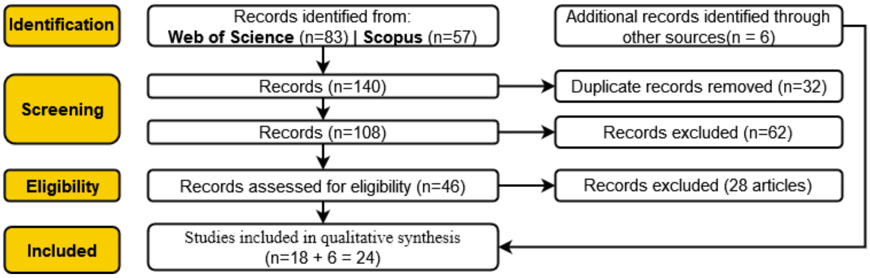

Figure 1. Flow chart diagram of the selected studies

The following section synthesises what was extracted from an in-depth content analysis of the identified articles concerning the general framework and competitive environment in which ETO operates. This type of company's principal characteristics and organisation is related to the actual challenges and issues.

3. Findings and discussion

ETO companies are characterised as higher value-added product fabrication, with a high customisation level, dedicated to low volumes production of small batches or one-of-kind products. These companies are project-based organisations, as shown in figure 2. Their main activity focuses on new product design and its manufacturing and assembly, the production activity with a very small lot size or one-of-a-kind and a wide variety of product mix. Their processes are rather complex [7] and have a high technical and technological specialisation level, requiring flexibility and qualified workers. ETO companies are customer-centric [8], which means their product development is always done with strong customer participation or involvement. Due to the uncertainty and complexity in the initial phase of customer product characteristics, the purchase of raw material and the production of the product designed only start after the confirmation of customers’ order quotations.

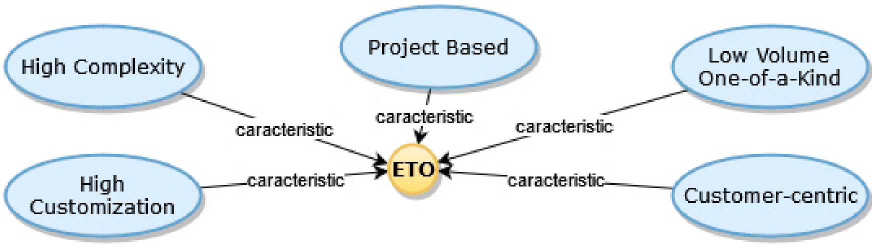

Figure 2. ETO main characteristics

3.1. ETO main issues

According to Sjøbakk et al. [9], the concern for achieving better performance in this company type arises because of a demand for increasingly customised products. The growing need to provide these customised products has reinforced the interest in studying the ETO production strategy. Due to the variety of work at ETO companies, the shop floor workflows are discrete, resulting in high managing demands [10]. As a result, higher decision-making resilience to workflow performance is needed [11] [12]. Value chain information management is a challenge in the ETO companies' dynamics environment at a tactical level [13]. In addition, the costs and delivery dates forecast uncertainty at the contracting stage. The lack of collaboration creates barriers to information processing, resulting in higher manufacturing costs [14], longer lead times, higher inventory costs, transportation costs and other supply risks. Planning is a complex task due to the combination of the multiple departments or areas of technical responsibility, the variability of lead times, and difficulties in predicting the workload of resources [15] [16]. Husejnagić & Sluga [10] state that the customer can be involved in all project stages, such as design, production, assembly and testing [17]. During this workflow, it is common to have several interactions between the customer and those responsible for the work in progress, defining and validating decisions taken during the manufacturing process. Therefore, customers can define the product characteristics at an early stage and introduce changes during the project, which often results in manufacturing process delays [18]. According to Gosling et al. [19, 20], late changes in engineering design can cause costs to increase and will affect resource allocation along the value chain. This involvement of customers in the company and the various interactions place a high demand on production planning and control activities [21]. One-of-a-kind products (or low-volume batches) increase the number of jobs pending in manufacturing [22].

3.2. Technical and scientific solutions

Barbosa & Azevedo [11] state that the assembly phase is a long process, sometimes critical and highly variable. While *Hong & Leffakis* [23] express great concern with customer demand variability as a level of incoherence or volatility in which customers place orders with the company. The dynamics associated with them are due to the numerous changes throughout the value chain, the complexity of the raw material flows, the number of parts related to each final product, and the projects spread across all the company's departments [24]. Due to its unique nature, there is no pre-existing design that allows how the production process will be, thus creating many product specification uncertainties that have a massive impact on the bidding phase [12] [25]. *Manzini & Urgo* [26] argue that uncertainty is an issue that affects project-based companies due to the complexity of the products and the level of customer customisation. Demand volume uncertainty is related to new orders from the customer, i.e., forecasting people and materials is a challenge when the company does not know the order start date. Manufacturing processes form uncertainty from the difficulty in estimating the number of machines, materials and human resources when product components are still unknown. When this happens, uncertain situations such as capacity, lead time and project costs are difficult to predict [27]. It is difficult for ETO businesses to precisely anticipate the production schedule at the contract stage [14] [16] [28] [29]. Issues such as lack of details in customer designs make it difficult to guarantee delivery dates [21]. Customer projects have a high complexity at the product and process level, resulting in increased costs and scheduling delays, forcing project managers to rethink their projects to resolve the issues. Due to one-of-a-kind or complex product manufacturing and assembly, ETO companies are subject to several problems at different value chain stages [22]. *Centobelli et al.* [30] propose layout change and a technological solution for the industrial installation's feed system to reduce production time. However, the customer's constantly changes would result in a layout replanning. *Mourtzis et al.* [28] present a mobile app for scheduling short-term job shops. This solution's potential lies in a well-documented historical record of operations. *Birki et al.* [31] implemented a lean strategy to assist performance in an ETO environment. Companies' performance may be different. Other evaluating references are needed. *Gössinger and Plitt* [21] developed an optimization-based approach to order liberation to solve an uncertain completion time issue. Model Reinforce to deal with information increases are needed. *Villar-Fidalgo et al.* [14] used Kanban panels to manage PERT-CPM network activities during project execution. *Brachmann and Kolisch* [1] suggested a novel mathematical approach to address engineer-to-order scheduling in tactical planning. *Duda et al.* [7] used the Quick Response Manufacturing (QRM) concept to reduce the time needed to respond to order requests. *Micale et al.* [16] developed a framework for the planning process at the tactical level. *Li* [29] developed a hyper-heuristic improved genetic algorithm to handle a job scheduling issue. *Lokkegaard et al.* [32] developed a method for identifying reference architectures in consideration of profitability. A tactical-level planning process framework for the fulfilment process was developed by *Shurrab et al.* [33], as shown in Table 1.

Table 1. Systematic literature review approaches.

#	Issues	Approaches	Contributions	Weaknesses	Year	Ref.
1	Bid solution uncertain	A multi-criteria approach to bid solution uncertainty	Provides bid solutions with accurate and timely replies.	Single case study with limited data.	2017	[25]
2	Bid solution uncertain	Interactive bid solution evaluation	Allows bidder's best solution selection.	Many decision criteria increase the time consuming.	2021	[12]
3	Capacity planning	Tactical capacity planning with an optimisation model.	Improved tactical planning decision-making.	Insufficient case studies.	2016	[27]
4	Configuration process delays	Framework to identify and compare products' similarities.	Complexity, engineering time reductions	Variables may affect the coding of IT systems inefficient.	2017	[34]
5	Design specification	A stochastic dynamic model.	Extended the scope of research on project scheduling.	Limitations in large project resolution	2017	[35]
6	Detail specifications.	An optimization-based approach to order liberation.	Extends MTO-specific order release to ETO.	The basic model doesn't consider information increases over time.	2019	[21]
7	Frequent changes.	Design Science Research's Lean Project Management approach.	Combines lean efficiency and flexibility.	Needs dynamic and agile approaches to real challenges.	2021	[18]
8	Long lead times	Simio software simulation	Costs reduction Short lead times.	Each design change would result in replanning.	2016	[30]
9	Long lead times	Quick Response Manufacturing (QRM) concept implementation.	Hybrid architectures increase customer response.	Requires a most organised use of technology solutions.	2021	[7]
10	Low performance	Implementation of the lean practice	A greater extent of lean increases sustainability.	The need for more references to evaluate performance.	2017	[31]
11	Performance assessment	An integrated hybrid model for performance evaluation.	Optimizes system performance and selection.	Special projects become more uncertain and difficult to assess.	2018	[11]
12	Planning and Control	Asaichi with visual control and management technologies.	Reduces unnecessary operations and increases efficiency.	Insufficient case studies.	2018	[15]
13	Poor workflow visibility	RFID data collection system.	Real-time information sharing. Costs reduction.	Limited to box transportation due to transponder fixture.	2014	[36]
14	Process planning	A tactical-level planning process framework.	Forecasts potential medium-term capacity decisions.	The research focused on one order fulfilment procedure.	2022	[33]
15	Production planning	A commercial solutions	Help schedules location, due dates, and resource availability.	Multiple projects are scheduled with limited resources.	2021	[1]
16	Production scheduling	Kanban panels to manage PERT-CPM	Single Kanban-managed task and software availability.	Practical applications are required.	2019	[14]
17	Project management.	Lean project planning (LPP) and control framework.	Allows the control planning complexity analysis	The method should be tailored to each company and project.	2019	[37]
18	Quotation	Methodology to optimise ETO product design.	Time reduction. Several software combinations.	The tools aren't integrated into the same design platform	2019	[38]
19	Scheduling	A mobile application that schedules short-term job shops.	High-quality solutions.	The necessity for pre-existing and sufficiently documented cases.	2016	[28]
20	Scheduling	Production planning method for a multi-project ETO.	Provides four production scheduling models.	Insufficient case studies.	2021	[39]
21	Scheduling	A model for regenerative scheduling.	It also covers machine breakdowns or urgent orders.	NP-hardness, the problem size constrains the solution approach.	2021	[16]
22	Scheduling	A hyper-heuristic improved genetic algorithm.	Algorithm efficiency and practicality.	Restricted to large-size problems.	2022	[29]
23	The batch size uncertainty.	Bayesian uncertainty modelling	Reduces the input uncertainty on cost estimation	Restricted and slow data collection.	2017	[22]
24	Unstructured knowledge	A method for identifying reference architectures under the consideration of profitability.	It enhances customer solutions and reduces costs.	Additional tests and an assessment of the effects over a more extended period are needed.	2022	[32]

Table 1 identifies the several issues and approaches resulting from SLR. With the information obtained, it is possible to create clusters of issues, such as planning problems, capacity problems, lead time problems, and bidding and scheduling solutions. Although some issues are shared between studies, the solutions proposed by the authors are varied. One way to visualise these problem associations is through a concept map (figure 3) where the ETO companies and their characteristics are in its centre. In the second ring, the issues are presented. In the third ring, the authors' proposals and outside the last ring, their contributions and weaknesses.

This map will identify the problem area more intuitively and the studies' weaknesses.

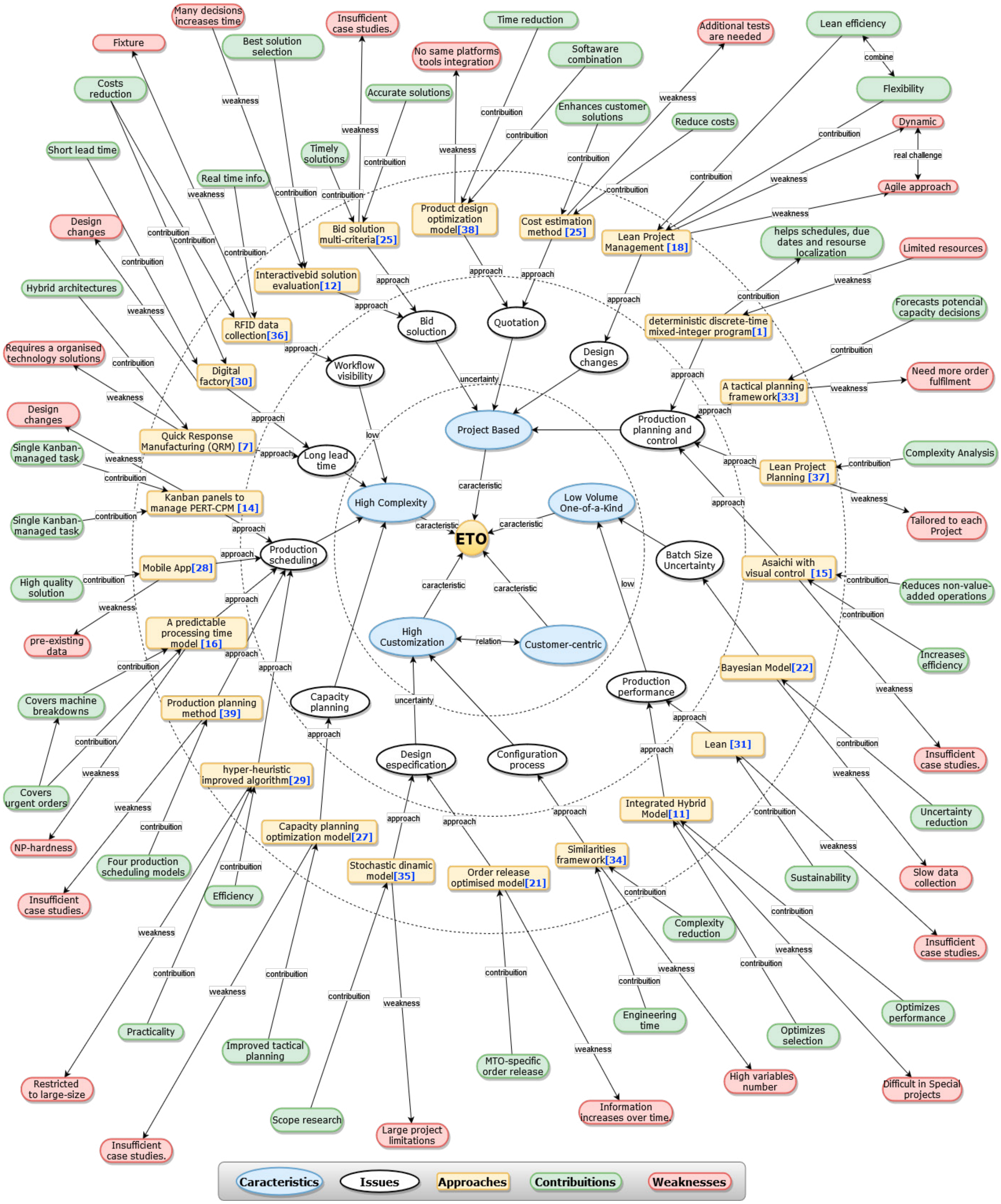

Figure 3. ETO concept diagram

4. Conclusion and Future work

In ETO companies, manufacturing and assembly activities require strict tactical and operational planning to ensure compliance with delivery dates. This planning is challenging due to ETO companies being multi-project production systems driven and constrained by capacity and delivery schedules, which means that resource shortages can compromise operations and customer satisfaction. In addition, the workflow on the shop floor is strongly affected by the high variability associated with the manufacture of one-of-a-kind components or in small production batches, where the process plan of each component differs in its sequence, the operations, and the times associated with each operation. Consequently, activities such as process planning, material requirements planning, capacity planning, task sequencing and demand management are essential activities that companies should perform daily to meet customer demands and to be consistent and sustainable in their competitive environment. The characteristics that define the ETO production systems, their organisation and the competitive environment in which these companies operate were provided in this LR. Several limitations of this study should, however, be highlighted. One of the limitations was the fact that only articles from 2017 up to the present have been considered. However, this study refers to May 2022, and since then other studies have been researching due to the importance of this matter. Challenges and issues that generate barriers in the value chain and recommended solutions for their resolution or mitigation were identified. However, new planning and management approaches are needed to enable companies to respond to workflow obstacles resiliently. These approaches to achieve excellence in planning and management activities must consider the I4.0 paradigms to consider effective implementation technologies or tools that will support more efficient use of methods or methodologies to support simultaneous decision-making in planning new orders, managing the workflow and the use of resources. Techniques to model and support decision-making based on past, present (real-time), and future forecasts about the available capacity are crucial in improving workflow resilience. Developments must be driven by their ability to mitigate the most relevant identified difficulties. As further steps, the aim is to use the results of such analysis to conceive, design and create a new approach or solution to be proposed. The new approach or solution should focus on the resilience of the workflow in the ETO companies for efficient resource management and meeting deadlines.

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