Understanding dynamism and complexity factors in engineer-to-order and their influence on lean implementation strategy

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Abstract

Complexity and dynamism are considered intrinsic features of engineer-to-order (ETO) business environment; it is, therefore, important to understand and manage them better. Based on empirical investigation of two case companies, this paper expands existing literature on how and why complexity and dynamism context factors constitute not only external business environment issues but also sub-factors within the boundary of the firm. It argues that most of the sub-factors for complexity and dynamism identified for repetitive manufacturing are relevant for the high uncertainty capital goods manufacturing ETO with some exceptions such as short product lifecycle and technological turbulence. A framework of configuration (on implementation of lean practices), and moderation (on the lean-operations performance relation) forms of influence from dynamism and complexity is proposed. Further arguments to be verified in future large scale research include: (1) dynamism bears challenges, and complexity provides opportunities to foster implementation of relevant lean practices in ETO, (2) both complexity and dynamism positively mediate better operations performance and enriched value from implemented lean practices.

Keywords: lean, engineer-to-order, dynamism, complexity, uncertainty, case study

1 Introduction

AB Italy, part of ABC group, is an engineer-to-order manufacturing company which has been working with a lean excellence consultancy company to implement lean practices for over three years now. Lean implementation has been a tradition for long time in the parent company. AB's management team is convinced that several improvement benefits have been and will be achieved with this effort. However, they feel that in some areas of the business functions, the use of lean practices is not so direct and clear especially with the one-of-a-kind production business nature.

Proponents of lean production argue that lean thinking should be 'universally applicable' (e.g. Womack and Jones 2003), despite the type of business strategy followed and sector of

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application. Others argue that it is more suited for large volume production than small volume high variety production (Cooney 2002; Naim and Gosling 2011) or engineer-to-order (ETO) as in AB. However, empirical evidences in support of or against these claims are fairly limited (Gosling and Naim 2009). Despite widespread research and publication on lean, there is dearth of evidence addressing peculiarities of implementation in different business environments including capital goods manufacturing ETO.

Only recently has the influence of context factors (such as complexity and dynamism) on the relationship of lean implementation and performance benefits become a focus of research. For example, Browning and Heath (2009) argue that lean practices could lead to negative returns beyond a certain level of implementation in the presence of instability and uncertainty. Azadegan et al. (2013) found out complexity and dynamism of the environment significantly influence the performance achievements from the lean implementation in repetitive manufacturing firms. We also know that complexity and dynamism are relevant in describing characteristics of ETO environment (Adrodegari et al. 2015; Gosling, Naim, and Towill 2013). The limited consideration of these context factors in lean implementation studies as well as the motivation of some ETO firms in capital goods manufacturing industry to implement lean (e.g. Portioli Staudacher and Tantardini 2008) lead to interesting questions of practical and theoretical relevance.

The aim of this study is to deepen our understanding of how complexity and dynamism factors influence lean implementation strategy in non-repetitive production, by investigating capital goods ETO environment. It also intends to better understand what complexity and dynamism factors constitute in the same environment. Hence, the theoretical contribution of the paper is twofold, aiming at characterising what are the constituents of complexity and dynamism factors in ETO, and how they might affect lean implementation strategy in the same context. It is also practically relevant to generate managerial insights to evaluate if lean implementation in such environments is worth the effort. Understanding complexity and dynamism better could pave the way for redefining lean in high uncertainty context, leading to further insights on how lean should be implemented to maximise benefits in such environments. Broadly speaking, this study contributes to the dilemma in literature about suitability of lean by drawing attention on the relationship of the constituents of the problem.

The remainder of this paper is organised in the following manner. Section 2 provides brief theoretical discussion of lean, along with the ETO empirical context. Research questions and adopted qualitative method of research are presented in the third section. Section 4 presents empirical findings from an in-depth primary case study on complexity and dynamism factors, and their influence on lean strategy in ETO capital goods manufacturing; a secondary case is added for reasons discussed later. The findings are discussed in section 5, and conclusions are drawn in section 6.

2 Theoretical understanding of lean and context of implementation

2.1 Lean production

Shah and Ward (2007, 791) define lean production [lean for short] as 'an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing or minimising supplier, customer, and internal variability'. Lean encompasses a broad perspective ranging from strategic to tactical levels. It constitutes guiding principles on processes, people and partners, problem solving, and long term thinking that are translated into implementation in form of relevant practices (Liker 2004; Womack and Jones 2003). For example, Shah and Ward (2003) describe lean as bundles of consistent practices.

Shah and Ward (2003) describe lean as bundles of consistent practices, i.e., categories of logically interrelated practices that businesses can exploit to enhance their competences. Just-in-time (JIT), total quality management (TQM), total productive maintenance (TPM), and human resources management (HRM), are lean practice bundles that focus on internal processes. Other practice bundles like active involvement of customers, collaboration, lean purchasing, and long term relationship with suppliers focus on 'external connections' (Shah and Ward 2007; Inman et al. 2011). The use of practice bundles approach provides an 'intermediate' level construct connecting strategic and philosophical aspects of lean with the tactical level, consistent with the definition of lean adopted in this paper.

Table 1 presents a comprehensive list of practice bundles suitable for the purpose of this study summarised from different literature. It also lists practices under each bundle. Different authors proposed a varying number and arrangement of practice bundles for operationalising lean (Marin-garcia and Carneiro 2010; Taylor, Taylor, and McSweeney 2013; Shah and Ward 2007; Shah and Ward 2003). However, regardless of the difference in number of bundles, the underlying practices in those papers are mostly consistent. Among these, Shah and Ward (2003; 2007) provide statistically reliable way of forming the practice bundles.

Table 1. Lean practice bundles and their underlying indicators

Practice bundles	Some underlying indicators	References
TQM and visual management (VM) - (continuously improve and sustain quality)	Quality management programs Formal continuous improvement programs Process capability measurement Use of proper visual tools	(Shah and Ward 2003)
JIT/ Flow – (flow and continuously removing waste)	Cellular layout Bottleneck identification and removal Cycle time reduction, Reengineering processes Quick changeover techniques	(Shah and Ward 2003)
HRM- (building the human resources as per needs of lean implementation)	Job rotation, design, and enrichment Formal cross-training programs Problem solving groups and employee involvement Flexible cross-functional work force	(Shah and Ward 2003)
Lean purchasing (LP)	Reduced purchase order sizes Short order placement processes Reduced need for incoming material inspection	(Inman et al. 2011; Azadegan et al. 2013)
Customer involvement and partnership (CIP)	Customers' direct engagement in product offerings Customers' feedback on different performances	(Shah and Ward 2007)
Supplier involvement & development (SID)	Close contact and long term relationship Supplier development and certification Improvement commitments from suppliers	(Shah and Ward 2007)
Standardisation (STD)	Standardising processes and procedures	(Marin-garcia and Carneiro 2010)
TPM- maximisation of equipment effectiveness	Maintenance optimisation techniques Preventive/predictive maintenance techniques New process/technology acquisition	(Shah and Ward 2003)

2.2 Lean in the ETO business environment

Engineer-to-order (ETO) refers to a manufacturing mode in which the customer actively collaborates starting with the concept engineering phase of the product lifecycle in order to develop (and manufacture) a product that meets the customer's functional requirements. It can be seen as a supply chain arrangement or set of strategies followed in manufacturing (Chen 2006; Gosling and Naim 2009; Narasimhan, Swink, and Kim 2006). ETO can be regarded as a continuum of strategies (Olhager and Östlund 1990) to realise uniquely designed products for specific needs (Forsman et al. 2012).

In its classical form, the ETO product development process starts with requests and specifications from customers for each order and ends with an engineering design. Contemporary ETO often engages in both engineering as well as manufacturing of goods in small quantities (Chen 2006). A major driver of the ETO business environment is that the company and the customer agree to respectively sell and buy some products that did not yet exist (Chen 2006). Detail features and mix of the final products are driven by customer orders through on-going negotiations and involve diversified organisational arrangements and product portfolio (Gosling and Naim 2009; Adrodegari et al. 2015). Therefore, some level of uncertainty for change prevails throughout the process.

ETO is normally adopted with the primary aim of responding to variety and customisation needs (Adrodegari et al. 2015; Jiao, Zhang, and Pokharel 2005). Traditionally, price was not the main issue in ETO as long as the agreed quality levels were met. However, with tightening economic conditions, pursuing better efficiencies are becoming vital. Furthermore, short concept-to-delivery lead time is becoming a competition lever in ETO. At the same time, late change requests on specification need to be entertained. These challenges appear to motivate ETO firms to try out lean practices (Portioli Staudacher and Tantardini 2008). The challenge is that in ETO several context factors may affect the way lean practices are implemented (Böhme et al. 2014; Veldman and Klingenberg 2009).

Several authors suggest that lean is more applicable towards repetitive manufacturing than ETO-like supply chains, even though both lean and agile strategies have been suggested for the ETO environment (e.g. Naim and Gosling 2011). Increasing customisation required in products and processes coupled with the need to respond to customers' requests in real time for ETOs appears to attract more discussion of agility than leanness.

Literature on the investigation of lean practices in the ETO environment is limited compared to that of mass production or batch type systems. Table 2 summarises key issues discussed in the literature regarding lean with implications for implementation in ETO environment. As can be clearly seen from the table, there is interest to understand the ETO context in connection with lean practices implementation. Lean implementation in ETO implies waste identification and elimination in one-of-a-kind manufacturing (Cutler 2009) which is not so easy as in repetitive manufacturing (Browning and Heath 2009). It follows from the literature that lean implementation is subject to uncertainties that prevail in ETO companies (Cooney 2002; Böhme et al. 2014; Veldman and Klingenberg 2009).

Table 2 shows, based on our literature search, that empirical investigation in ETO for lean implementation and related context factors is limited. Previous studies argued that complexity and dynamism context factors have detrimental influence on how lean bears on performance. However, evidence as to whether this holds true under the particular nature of ETO environment is sparse. In order to pursue with this discussion, uncertainty context issues of ETO have to be explored and better understood (Browning and Heath 2009; Chavez et al. 2013). To the best of our knowledge, there are scarce explorative and explanatory studies investigating complexity and dynamism factors in ETO and particularly in capital goods

Table 2. Lean implementation in ETO: main issues discussed in literature

Literature	Focus on investigation and implications for lean implementation in ETO	Sectors/application	Applied methodology
Azadegan et al. (2013)	Investigates how dynamism and complexity affect lean implementation; investigation of the effect of these factors could be more interesting in ETOs as they have more dynamic and complex context	Manufacturing	Regression analysis on primary and secondary data
Böhme et al. (2014)	Lean practice bundles for mass production can be adopted to ETOs by addressing prevailing uncertainties	Engineering ETO	Case analysis
Browning and Heath (2009)	Relation of lean implementation on production cost with moderating factors; Uncertainty and complexity significantly influence benefits of lean; timing and extent of application determine success	Aerospace manufacturing	Case study, longitudinal
Chavez et al. (2013)	Internal lean practices improve multiple operational performance dimensions and industry clockspeed (rate of change) moderates it; dynamism in the business environment is key factor in lean implementation	manufacturing	Regression analysis on survey data
Cooney (2002)	Argues that lean is not universally applicable as a stand-alone production system; Lean implementation in ETO questioned as only some lean practices appear to be relevant and achievable	luxury vehicle manufacture	Case study, multiple
Cutler (2009)	Discusses challenges of ETO for implementing lean as this involves waste elimination in one-of-a-kind manufacturing; Lean metrics in ETO may need to be adjusted to address specific features of ETO	Unspecified (manufacturing)	Conceptual paper
Elfving et al. (2005)	Investigates that competitive bidding increases overall lead time of ETO projects; lead time improvement opportunities in ETO using the concept of lean demonstrated	Power distribution	Action research in purchase process of equipment
Eroglu and Hofer (2011)	Investigates relation of inventory leanness with firm performance; industry-specific inventory management proposed (that takes into account ETO needs too)	Manufacturing	Regression analysis on data from established database
Forsman et al. (2012)	Investigates areas of innovation in ETO to improve efficiencies; long term supplier relationship and efficient communication found to have improved efficiency in ETO	Construction ETO	Case study
Gosling and Naim (2009)	Contend that there is not enough empirical study justifying the applicability (or otherwise) of lean in ETO; characterising ETO should help for large scale investigation of lean implementation appropriateness	Unspecified	Literature review
Gunasekaran and Ngai (2005)	Proposes framework for build-to-order supply chain (BOSC) design and management issues; Call for further studies on implementation of BOSC issues, including JIT and IT for integration	Unspecified	Literature review
Matt (2014)	Application of value stream mapping (VSM) and analysis in ETO: opportunities of reducing waste	Focus on ETO	Literature review with case
Veldman and Klingenberg (2009)	Following capacity maturity model most lean best practices can be applied to ETO kind manufacturing but the model has to be enhanced to reconsider less applicable ones like JIT	Capital goods, oil and gas	Conceptual paper with case analysis
Votto and Fernandes (2014)	Proposes methodology to apply lean philosophy and theory of constraints (TOC) jointly in ETO; joint implementation of lean principles and TOC argued to have reduced lead time and improved dependability	ETO capital goods	Action research

manufacturing. We believe an in-depth qualitative approach is a good way for such better understanding.

2.3 Dynamism and complexity as context factors

According to contingency theory, performance of an organisation depends on how strategies and structure in the organisation are aligned with contingent factors in which the organisation operates (Duncan 1972; Swamidass and Newell 1987; Zhang, Linderman, and Schroeder 2012). The results of lean implementation are subject to influence from context issues including complexity and dynamism (Azadegan et al. 2013; Chavez et al. 2013), size (Shah and Ward 2003), and human issues (Taylor, Taylor, and McSweeney 2013) to mention some. The concern of this study is complexity and dynamism as uncertainty context factors which are related to heterogeneity and unpredictability (Dess and Beard 1984). ETO environment provides a suitable study setting for investigating these context factors as it is characterised by high environmental uncertainty (Adrodegari et al. 2015).

Starting with Duncan (1972), several scholars have studied complexity and dynamism factors in different industrial settings. These high level constructs are considered to represent environmental uncertainty of business organisations. Complexity mainly describes the number and similarity of factors considered in a decision making situation; dynamism refers to the degree to which these factors continually change over time (Dess and Beard 1984; Duncan 1972). The two factors are further categorised into internal (related to organisational personnel, function, level) and external (related to customers, suppliers, socio-political, competitors, and technology). Synthesis of the complexity and dynamism context factors from literature is presented in Table 3 in the internal and external subdivisions for each.

Some of the literature reported in Table 3 (e.g. Wong, Boon-itt, and Wong 2011) did not particularly discuss lean implementation in addressing the uncertainty context issues.

However, their operationalisation of the context factors makes them relevant for the current discussion, even though some variations of these sub-factors are noted.

Table 3. Complexity and dynamism context factors as compiled from reviewed literature

Factors	Sub-factors	References†							
		P1	P2	P3	P4	P5	P6	P7	P8
Complexity, Internal (CI)	1. Product diversity and novelty		✓	✓		✓			
	2. Production process interdependences	✓		✓	✓				
	3. Variety of interactions (i.e. decision making)	✓			✓				
	4. Composition of skills and competence necessary in the business	✓							
	5. Organisational goals and objectives (inconsistency of)	✓							
	6. Short average.- product lifecycle		✓	✓					
Complexity, External (CE)	1. Diversity of inputs			✓		✓			
	2. Diversity and number of customer segments for major products/services	✓	✓	✓		✓			
	3. Suppliers and sub-contractors involved	✓	✓			✓			
	4. Regulatory requirements	✓							
	5. Extent of technological requirements to meet	✓							
Dynamism, Internal (DI)	1. Internal performance issues (technology workforce)					✓	✓		
	2. Rate of innovation		✓						
	3. Changes in modes of production		✓						
Dynamism, External (DE)	1. Change in customer demographics		✓					✓	✓
	2. R & D expenditure changes		✓						
	3. Demand unpredictability and instability		✓		✓	✓			✓
	4. Suppliers' & sub-contractors' performance predictability		✓		✓	✓			
	5. Predictability of competitors' actions/pressure					✓		✓	✓
	6. Changes in regulatory requirements		✓					✓	

† **References:** P1: (Duncan 1972); P2: (Azadegan et al. 2013); P3: (Sousa and Voss 2001); P4: (Browning and Heath 2009); P5: (Dess and Beard 1984); P6: (Wong, Boon-itt, and Wong 2011); P7: (Swamidass and Newell 1987); P8: (Zhang, Linderman, and Schroeder 2012)

Prevalence of complexity and dynamism often implies the need to be responsive, agile, and efficient (Naim and Gosling 2011). This appears to reinforce the arguments for the limited applicability of lean in such environments by some scholars. However, recent studies provide more detailed information of how lean practices affect performance in environments where complexity and dynamism are high. Azadegan et al. (2013), Eroglu and Hofer (2011), Zhang et al. (2012), and Browning and Heath (2009) are among the few studies that considered influence of dynamism and complexity context factors in relation to lean and quality management. Arrows A1 and A2 in Figure 1 represent the moderation role proposed in literature and discussed, for instance, by Azadegan et al. (2013) with reference to a repetitive manufacturing context. That is, complexity and dynamism influence the operations performance benefit of the implemented practice bundles. This same logic applies to ETO as it is characterised by high environmental uncertainty (Adrodegari et al. 2015) with high complexity and dynamism (Duncan 1972).

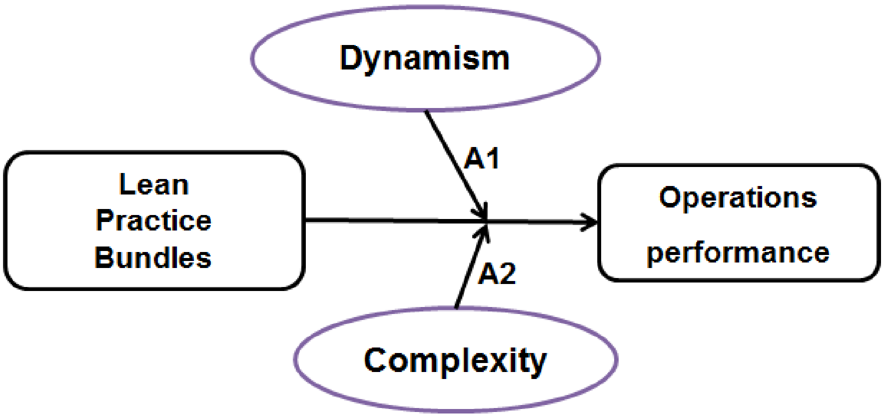

Figure 1. Moderation role of complexity and dynamism uncertainty factors

Browning and Heath (2009) discuss how the interplay of complexity and dynamism factors affects lean implementation and cost performance. Industry features (e.g. sector, process complexity, supply and demand characteristics) are some factors found to have influence in determining the relationship of leanness with performance benefits (Eroglu and Hofer 2011). Azadegan et al. (2013) show that environmental complexity (based on market structure) in different industry sectors positively influence the relation of both internal lean operations and lean purchasing (externally focused) practices with operations performance. They also found that dynamism negatively influences the relationship.

In the aforementioned studies, the levels of detail in their operationalisation of the constructs are different, and most of them have focused on external (industry level) context issues. While external factors are very important, there is a lack of investigation on how internal complexity and dynamism sub-factors might influence lean implementation strategies. Another observation is that the (limited) studies focus on how the context factors affect the relationship between implemented lean practices and performance gains. The controversy on universal applicability of lean together with the findings on influence of uncertainty context makes an in-depth investigation in this area relevant and timely.

3 Objectives of the study and research methodology

3.1 Objectives and research questions

The influence of complexity and dynamism context factors in the implementation of lean practices has been studied mainly using industry level uncertainty factors. From extant literature we discussed in the previous section, these two context factors can be viewed to include aspects internal to a manufacturing firm as summarised in Table 3. However consideration of these aspects while investigating lean implementation is limited. The current study intends to address this gap. Since complexity and dynamism significantly moderate the effect of lean practices on performance (Azadegan et al. 2013), their influence should be much more apparent in ETO context where they are intrinsic features.

We consider the capital goods manufacturing ETO sector as an appropriate domain of investigation as it is often run in combination with other order fulfilment strategies from which some relevant practices are borrowed. The interest of ETO firms in implementing lean in this sector makes investigation practically relevant to explore if the lean efforts in such environment are worth. As stated, this study aims to better understand constituents of complexity and dynamism factors in capital goods ETO and investigates if these factors have differences from those that apply in repetitive manufacturing firms, as reported in extant literature. It also intends to explore and better understand how these context factors affect implementation of lean practices in the same ETO firms. Accordingly, the following research questions are set forth.

RQ1: What are the peculiarities of complexity and dynamism factors for ETO firms in capital goods manufacturing?

RQ2: How do complexity and dynamism influence lean implementation strategy in ETO capital goods manufacturing firms?

3.2 Methodology

The methodological approach used for this paper is case study. Case study provides good internal validity and opportunity to investigate context factors in detail (Yin 2003) while replication and sampling frames are its challenges (Eisenhardt 1989). There is ample literature regarding lean practices in general but detailed empirical investigation of its implementation in ETO context is limited. This means that we do not know practically well if and which practices are implemented. Empirical investigation is also lacking about context issues in ETO that may influence lean implementation, which is the major concern of this study.

We start from lean practices and uncertainty factors in established literature in order to discuss and explain specification of the lean practices and uncertainty context issues in ETO. Therefore, detailed exploration in single (or a few) case investigation is prioritized as generalization is not a primary concern of this study. Given the aforementioned considerations, in-depth case study is appropriate and justified for this study as it helps to closely engage and investigate the phenomena in detail in a real-life situation (Yin 2003). Based on the findings from the in-depth case study, a secondary case is added later. This was done to replicate and build insights on the findings of the primary case regarding the influence of the context factors in a similar ETO context. Since replication logic is followed for this second case, sampling criteria and case sample sizes are irrelevant (Yin 2003). There are several studies that used two case studies in similar fashion as this study (though not necessarily in sequence as we did). For example, Erlandsson and Tillman (2009) have used two cases to develop framework regarding drivers and barriers of corporate environmental information collection; Wang and Chan (2010) compared and contrasted two cases of dissimilar organisations to discuss the role of virtual organisation for integration of activities.

The in-depth primary case study was conducted in a major subsidiary (hereafter called AB) of a multinational parent company (hereafter called ABC Group). Empirical investigation details refer to the Italian country unit of AB. AB's main business is design and manufacturing of capital goods. AB's business is dominantly based on ETO and assemble-to-order (ATO) manufacturing modes while ABC Group is dominantly mass manufacturing. Choice of the particular company for this study was motivated by its engagement in ETO manufacturing with relatively recent experience of implementing lean, while the parent company has mostly repetitive manufacturing with strong long lasting experience of lean implementation.

Data collection in the primary case company was done using multiple sources and methods (Yin 2003) from November 2013 to March 2014. Semi-structured interview sessions of 7.5 hours in total with six managers from different functions (production planning: 4.5 hours in 4 sessions with three managers, and one session with each of procurement: 1 hour, quality management 1 hour, and engineering and design: 1 hour) were administered. The interview questions were developed based on several hours of brainstorming sessions among the researchers and managers from different departments in the company, and review of company documents on lean implementation progress. They were aimed at letting the managers explain the change process and challenges faced in as much detail as possible from which context issues and influence on implemented practices were identified for reconciliation with available documents. Some of the questions posed to the managers are listed in Appendix 1. The interviews and follow up sessions were recorded and transcribed.

To further enrich our understanding of the business environment, we had several hours of field observation at the shop floor as well as 10 hours of participation in cross-functional meetings and follow-up discussions. *The researchers who attended the sessions took field notes and asked for clarifications as necessary afterwards. Some sessions were also recorded as well, but not transcribed. These were checked against the company documentation, and were used to the subsequent interviews.* We collected copies of reports and excerpts of datasets. These include documents regarding lean implementation in shop floor, collection and analysis of identified problems, initiatives taken during the change process, reports from previous studies, as well as extracts from an order registry file.

As a result of the findings in the primary case, we have additionally discussed a secondary ETO case company (hereafter called HCC) from the same industry implementing lean. HCC combines a form of Build-to-Order and ETO manufacturing modes. The company has been implementing lean practices since 2004 with stringent efforts. The discussion of this secondary case is based on secondary data and more concise than the detailed primary case. Indeed, it is intended to show how the context factors identified and detailed in the primary case study may apply to more than just a single firm within the capital goods sector. The use of empirical evidence about influence of uncertainty context factors on lean implementation from multiple cases is used as a way to improve external validity mainly for those mechanisms that are scarcely addressed by extant literature.

In both case studies we used established lean practice bundles (Table 1) together with relevant uncertainty context factors (Table 3) to investigate lean implementation in the ETO context. The collected data was analysed qualitatively to identify patterns in ETO with reference to lean practice bundles presented in Table 1. Extent of implementation of lean practices under each bundle are rated as low (L), medium (M) and high (H) levels for each case. This is subjective assessment of the researchers based on patterns in Likert scale measures for assessing implementation of practices (e.g. Demeter and Matyusz 2011) and lean enterprise self-assessment tool (Nightingale and Mize 2002; Jørgensen et al. 2007). A similar scoring approach has also been used in the Marino Associates' self-assessment checklist (Marino Associates 2005). Appendix 2 describes the extent of implementation for the practices in each bundle to be considered high, medium or low.

Chronology of events, as well as asking for explanation of phenomena were used to establish better internal validity as suggested by Yin (2003). The use of multiple data sources and the opportunity to ask follow up questions after meetings and reading documents helped us to enhance triangulation (Eisenhardt 1989).

4 Description of case studies and findings

4.1 Description of the primary and secondary case companies

The primary case company, AB, belongs to one of the three main business units of ABC. It has contributed about 13% (5.7 billion) of the 46 billion Euros annual sales revenue of ABC in 2013. Research and development expenditure has been growing continuously in over the past five years. ABC has more than 300,000 employees globally, of which around 36,000 belong to AB; the specific Italian country unit accounts for about 400.

AB produces diverse custom-made products including product categories of mobile and industrial hydraulics (e.g. power units, manifolds, etc.), electrical drive and control equipment. Each product in each of the categories involves very diverse list of custom designed and standard part numbers with several configurations for each.

The secondary case company in this study is Hytrol Conveyors Company (HCC). It is a US based company producing conveyor belts. HCC designs and manufactures a range of products from single unit to complete conveyer systems with various customisations to fit customers' requirements and technology. Main areas of application for its conveyor systems include warehousing, distribution, continuous flow and discrete item production. It serves customers in 13 countries from a single plant in US. Integration partners act as outsourced after sales service providers and sales representatives for HCC. The company management perceives that the efficiency and lead time reduction benefits gained with the implemented lean practices through the years are significant.

4.2 Findings on dynamism and complexity context factors in ETO

Most of the complexity and dynamism sub-factors summarised from literature have been observed to prevail in the case companies. Table 4 summarise the main findings of the study by providing evidence of how the two context factors (and their underlying sub-factors) are exhibited in AB. It also depicts that similar context factors were found later in the secondary case, HCC, while investigating influence of these factors.

In ETO capital goods, relationship with external actors can become overly complex. An illustrative example is a customer placing an order for which the customer itself is supplier of key components to be integrated in design and assembly of the product by AB. Introduction of these components affects the whole process and productivity, even worse if they are delayed since successive projects are also affected (Radnor and Johnston 2013).

The simple example illustrates how such situation may aggravate complexity and dynamism in ETO because influences from several sub-factors come into play: one more 'supplier' (external complexity) about which no information on performance is available in that role (external dynamism), and increased interdependence of processes (internal complexity) to mention few.

Table 4. Complexity and dynamism factors in ETO with evidence from the primary case, AB (and HCC)

(Sub-)Factors[a]		Evidence from interview and documents of AB	Evidence of sub-factors in HCC[b]
CI	CI1	1. 'We also create the description of main features of the equipment. That means [HJ123] is X litres of tank with motor pumps with certain KW power …we usually work on new ETO, it is always different, at least a little… Manifolds almost always are new'	1. Ranges from single conveyor to comprehensive conveyor system with controls (total solution) including locally available after sales service
	CI2	2. 'Material missing is the top problem we have right now. And missing material could be due to the effect that BOM is not complete, to the effect that the changes from the customer point of view are not managed… may be the BOM has been changed in the engineering department but information has not arrived in production"	2. -
	CI3	3. 'The chain to provide the information is too long. We have the customer, which usually starts to talk with the salesmen [of AB]. The salesmen report the information to the technical branch guy. And then the branch provides the information again to the drawing department…One problem is the too many passages for the information at the beginning'	3. -
	CI4	4. 'It is complicated because you cannot expect that everybody has very deep knowledge of every small aspect of such a complex matter…'	4. High knowledge and experience composition also at integration partners (associates) level
	CI5	5. 'We received a different rule that was a strategic goal to complete a yearly turnover of Y… so I told to the [workers that] we cannot stick to our, let us say, "lean" goal'	5. -
	CI6	6. Not applicable for capital goods industry	6. -
CE	CE1	1. '… Big projects with engineering, with customisations are often supposed to be made of difficult items which are used once every 5 years', '[requested] systems are so much customised that you cannot use "few father codes" for inputs'	1. Inputs diversity proportional to product diversity and customisation
	CE2	2. 'ETO business is not really constant. You cannot make perfect levelling of the production. You have big different in the value of single order. That means big project, small projects, going from 10000 Euros to 5 million Euros. It makes a huge difference…And someone has to check the demand because you have different trend in the short time…'	2. Customers from 13 countries with different application areas and local rules managed by 85 integration partners
	CE3	3. 'We have an internal engineering and design department and some external, 5 at least, "drawing" companies. Also for the production we have our shop floor here and X number of partners here in Italy'	3. Large number; but strategically moving to reduce and in-source activities
	CE4	4. This applies to the regulatory requirements (e.g. product and process certifications] that business customers ask for; these are as diverse as regulations in the location and industry of application the manufactured system	4. Ergonomic and safety considerations demanding; diverse local laws and codes
	CE5	5. 'The customer wants a very special item. He knows why. A very special item which is made of X with a very strange luck which is making coffee which smells flowers, and so on but this is what he wants. And you have never ordered it [before] because this is [this] first time that somebody asked you [for] that'	5. Integration of conveyor equipment with other technology to fit customer needs

(Sub-)Factors[a]			Evidence from interview and documents of AB	Evidence of sub-factors in HCC[b]
DI	DI1	1.	'…everyone in the engineering department works in many different ways. So one is designer at good level details the other one is not the same…'	1. The company states that manufacturing requirements are dynamic
	DI2	2.	High innovation in technical solutions, as every ETO order bears some level of uniqueness	2. The business includes designing, testing and implementing ideas for new models and systems
	DI3	3.	Was not possible to capture this issue in the particular study	3. -
DE	DE1	1.	'[In the past] we had customers who were asking only for our components which are built as series production. […]. They are more and more asking [us for] complete system'	1. -
	DE2	2.	AB's R & D expenditure in Euros increased in the last five years (remained the same as percentage of sales)	2. Continuing effort of R&D by involving integration partners and customers
	DE3	3.	'…We know situations are always different...We start working on it provide a drawing. And then … the customer says "oh it is too long it is too big, please do it again" …[the demand] is so unfixed that nobody is daring to say anything [in advance]'	3. -
	DE4	4.	'Suddenly this supplier is closed because he has gone in Romania; suddenly the customer is gone because he has gone in China [that it cannot provide you short time deliveries as before]'	4. -
	DE5	5.	'Our market is very stressfully aggressive'	5. Appears somehow predictable
	DE6	6.	Changes are proportional to the changes in customer, territory and application industry	6. Changes are possible but difficult to predict

Notes: [a] CI=internal complexity, CE=external complexity, DI= internal dynamism, DE= external dynamism

[b] Evidence from the secondary case HCC is brought forward and depicted here for convenience in presentation despite the sequence of conducting the study

Regulatory requirements (external complexity) and changes in regulatory requirements (external dynamism) sub-factors appears to be strong for both cases but the way they are manifested is through demanding customer requirements rather than directly imposed on the case organization's operation itself. The changes are also related to the changes in customer demographics and demand (external dynamism). Even the same customer may ask for varying approvals and certifications for products to be sent to territories of different regulatory conditions. Such changes together with diversity in inputs and increased subcontracting play their part in pushing complexity a step further.

Among the sub-factors relevant for repetitive manufacturing, short product lifecycle (internal complexity) does not appear applicable for the ETO case companies as capital goods have long operational life. Among dynamism sub-factors, we could not capture changes in mode of production (internal dynamism) in AB. It does not seem to have major relevance to ETO.

4.3 Lean implementation in ETO and the role of complexity and dynamism

Section 4.2 described findings on the identification of context factors solely based on the primary case. This sub-section reports findings from the primary and secondary cases which describe elements of the multifaceted relationships between complexity factors and the lean implementation strategy in ETO operations.

Management of AB believes that their lean implementation provided a new way of looking at current manufacturing methods as it is built on flexibility and workplace organisation. For them the lean implementation efforts are mainly motivated by the need to be responsive to rapidly changing customer requirements. Cost pressure in the market also favoured the implementation of lean practices. Maintaining an assembly line that can be re-configured and expanded fast without making previous investments obsolete is an additional motive. For AB service level, flexibility to entertain late changes in customer preferences, as well as dependability in meeting due dates are priority performance objectives while quality and cost are qualifiers. One of the interviewed managers clearly noted that lean implementation is relevant for their business considering challenging context issues. He stated: ‘ETO business is more difficult to manage. But there are some key issues of lean production which can be effectively applied and must be, […] of course not all concepts in lean can be used here…’

Table 5 reports how the different practice bundles explained in earlier sections apply and relate to lean initiatives in AB and HCC. It also briefly describes performance implications of the practice bundles in light of the influence from complexity and dynamism factors in AB based on the relative rating of low, medium or high described in section 3.2.

Having observed lean implementation and how the context factors seem to impact it in AB, we decided to do a secondary case (HCC) that could generate additional insights in the same empirical context. Findings from HCC are depicted in Table 5 as well. Accordingly, the table shows the number of complexity and dynamism sub-factors, along internal/external sub-category, that appear to affect implementation of each practice bundle in the case companies. The table (fourth column) also shows summary of operations performance (cost, quality, flexibility, speed, and dependability) improvements achieved in AB vis-à-vis the prevailing highly complex and dynamic context. This clearly shows that the high uncertainty context of ETO capital goods can benefit from the lean efforts. Practices in some of the bundles implemented in the primary case are further described in the following paragraphs as illustration.

TQM and visual management: Several formal continuous improvement processes and visual management such as Kanban cards, regular meetings and 5Why approach have been exercised in AB. We have participated in one of these sessions to see how they do it. Given the efforts, however, number of problems solved from the identified ones is very low and needs to be improved further. Some key performance indicators (KPIs) are defined to measure improvements including the critical bottlenecks of engineering processes. Further rectification and building positive understanding by the staff involved is yet needed though. The redundant data encoding (due to claimed rigidities of implemented ERP system) has created extra task without adding value to the customer; however, the company somehow used it in defining the KPIs. We have observed somehow stronger but comparable implementation of TQM and VM related practices in HCC as is shown in Table 5.

Customer involvement and partnership: Customers in ETO are engaged from the very beginning of the product conception due to the intrinsic business nature. It is not uncommon to see negotiations and different value enhancement arrangements including waiver of expenses associated with late changes in favour of long term customer relationships. In some instances industrial customers also act as component providers that they have to bring in the parts to complete assembly and final testing, also adding to the complexity. Delay of such items affects not only productivity but also customer service for items next on the line. In HCC's associates local presence to the customers gave them strong connection to strongly engage the customer and better align requirements and offers.

Flow/Just-in-time: ETO business is a pull system as it starts with a request from customer. Theoretically there is high potential for creating smooth JIT flow. However, since the process involves frequent changes and missing elements, the orders could be blocked somewhere in the process as evidenced in AB's Kanban cards. Some initiatives have been exercised in AB's production planning to smooth and level production at the assembly shop floor. One of the informants told us that they receive materials sorted for each job directly from the warehouse. 'At the beginning we have a lot of benefits from this', he says, 'in the last period, when everything was growing and growing, we again [start to] have problems because we have missing materials, we were missing things…' Cycle time reduction measures are also being undertaken but limited to production shop floor. Major bottlenecks for ETO resided at the beginning of the process, mainly engineering processes. HCC used a somewhat different approach of JIT by in-sourcing bottleneck operations, and promising short times to customers. They forced themselves to align cycle times to the promised due dates.

Standardisation: Standardisation is one of the tricky and challenging parts in ETO environment (Chen 2006). Definition of quality gates, creation of kitting area, classification of products into families and sizes, preparation of work procedures and guidelines are quotable practices at AB towards standardisation. In ETO product family formation can be considered as a radical move if well addressed (Portioli Staudacher and Tantardini 2008). The considerable variation among orders means that it is not always easy to set or follow a unique standard, which further magnifies the inertia to follow set procedures. We observed in the case company that completion of an ETO order provides moving reference to continuously improve the standards set previously. In HCC standardisation is reflected in the form of extensive usage of common processes and component platforms.

Table 5. Implementation of lean practices in the cases studies, and performance implications (in AB)

		Primary case (AB)			Secondary case (HCC)	
Bundles	Practices	Observations on practices (level [a])	Operations performance effects	Influence of factors [b]	Observations on practices (level [a])	Influence of factors [b]
TQM & VM	Quality management programs (QMS)	Quality gates and testing as part of main processes (M)	Faster identification of problems causing delay/excess cost for example, due to missing or wrong information and/or parts	4 CI 2 CE 2 DI 2 DE	Strong QMS implementation (H)	2 CI 4 CE 2 DI 2 DE
	Formal continuous improvement programs	5why approaches with Kanban meetings established (M)			Continuous improvements (H)	
	Use of proper visual management tools	Well established use of visual tools in production planning and shop floor (H)			Implemented visual tools (H)	
	Process capability measurement	(L)			(M)	
JIT/ Flow	Cellular layout	Workstations set based on major product families (H)	Service level (on time delivery) improved from 38% to well above the 80% target set (but not sustained)	3 CI 3 CE 1 DI 3 DE	Cellular layouts set (H)	1 CI 4 CE 2 DI 2 DE
	Bottleneck identification and removal	Resource levelling attempts at shop floor; design stage still bottleneck (M)			In-sourcing of bottleneck operations to improve JIT (H)	
	Reengineering processes	Initiatives exist but without strong integration (M)			(M)	
	Cycle time reduction	Some initiatives for reduction in engineering and production (L)			Cycle time reduction initiatives are encouraged through short delivery time promises (H)	
	Quick changeover techniques	(L)				
HRM	Job rotation, design, and enrichment	Operators take turns for kiting and other activities as appropriate (M)	Production due dates improved even with late start of assembly (localised gains)	4 CI 3 CE 1 DI 2 DE	(L)	1 CI 3 CE 1 DI 2 DE
	Formal cross-training programs	(L)			Team based functioning (H)	
	Problem solving groups and employee involvement	Use of engineering skills to solve inventory pile up (M)			Active problem solving engagement (H)	
	Flexible cross-functional work force	Initiatives to use teams from different departments (L)			Personal integrity of employees and thinking like a family (H)	
LP	Short order placement processes	No structured process observed (M)	Cost reduction in relation to purchasing process	4 CI 3 CE 1 DI 2 DE		1 CI 3 CE 1 DI 2 DE
	Reduced purchase order sizes	Yes, but mainly due to diversity of inputs; Kanban boxes used for common small components (M)				
	Reduced need for incoming material inspection	(L)				

CIP	Customers' direct engagement in product offerings Customers' feedback on different performances	Customers often initiate and engage throughout until order is delivered(H) Unstructured except for change request, delay or defect (L)	Directing flexibilities to provide better dependability for customers	3 CI 3 CE 1 DI 3 DE	Customers engagement due to local presence (H) Associates recommend better solutions aligning customers and business offers (H)	1 CI 3 CE 1 DI 1 DE
SID	Close contact and long term relationship Supplier development and certification Improvement commitments from suppliers	Close communication and long term relationship with suppliers (H) AB relies on existing high technical skills at suppliers (L) AB feels major suppliers are fast to make improvements; but challenges with ABC's plants (H)	Lower cost of manufacturing with higher flexibility (Internal inefficiencies are still challenging)	3 CI 3 CE 2 DI 4 DE	Some level of long term relationship (M) Some supplier development efforts (M)	2 CI 2 CE 1 DI 1 DE
STD	Process/procedure standardisation Modular components/products Error proofing Work order palletisation	Use of standard workstation elements; written procedures for doing offer (M) Product family by size (L) Quality gates, & kitting established (L) Palletising and Kitting (L)	Potential benefit on lead time reduction and quality improvement (achieved benefits need to be estimated better)	3 CI 3 CE 1 DI 1 DE	Extensive use of common process (H) And components platform (H) (H) (H)	1 CI 3 CE 2 DI 2 DE
TPM	Maintenance optimisation techniques Preventive/predictive maintenance techniques New process/technology acquisition				Plant-wide integrated approach (H) of Maintenance excellence is applied (H) (H)	2 CE 1 DI

Notes: [a] Level of implementation of practices subjectively encoded into three values of low (L), medium (M) and high (H); See Appendix 2 for description of each score.
[b] Number of sub-factors in each category: CI=internal complexity, CE=external complexity, DI= internal dynamism, DE= external dynamism, influencing the implementation of the corresponding practice bundle.

Lean purchasing practices: AB has started purchase and inventory rules based on delivery lead times. For example, non-critical items used in almost every assembly (C items) are replenished using transfer Kanban boxes. AB is able to reduce lengthy order placement processes through Kanban signals and regular replenishment (standard item), integrated ERP system (strategic components with short lead times). Critical items specific to an order and with very long lead times are challenging to forecast and respect due dates for final product.

5 Discussion

This section discusses the findings by first looking at how complexity and dynamism sub-factors are manifested in ETO. We then briefly discuss two roles of influence from the context factors on lean implementation strategy: moderation and configuration. Discussion of moderation influence of internal complexity and dynamism factors is held in section 5.2 which is incremental to existing literature. It also discusses a newly proposed configuration role of both internal and external uncertainty factors on lean implementation strategy in section 5.3.

5.1 Constituents of complexity and dynamism in ETO

The first research question sought to understand complexity and dynamism context factors in ETO. We identified context issues in ETO having reference from the limited literature on uncertainty factors in relation to lean implementation. The findings show that there is wider range of complexity and dynamism sub-factors in ETO capital goods manufacturing compared to repetitive manufacturing, in line with the argument that ETO features high complexity and dynamism. The sub-factors of complexity and dynamism identified in our ETO cases were arranged according to Duncan's (1972) classification of internal and external. They were then compared with uncertainty sub-factors summarized from literature (11 for complexity and 9 for dynamism as shown in

Table 3).

Earlier research on uncertainty context factors for lean implementation dominantly focused on external complexity and dynamism factors (e.g. Azadegan et al. 2013). Using qualitative investigation in ETO, this study complements this line of argument by identifying that both complexity and dynamism also include relevant internal sub-factors.

To address the first research question fully, we have identified peculiarities of these factors in ETO compared to repetitive manufacturing. Let us consider, short average product lifecycle, a complexity sub-factor for example. It is related to what some literature call technological turbulence (e.g. Chavez et al. 2013), and does not seem to have relevance in capital goods ETO. This is mainly because the industry of focus has relatively stable technology in terms of major output/process; besides, changes in technology are often determined before the order is agreed upon. The ETO manufacturer principally owns the core capabilities; it may not necessarily be the main owner of technology. Therefore, technological turbulence, which may be crucial for fast moving consumer goods (e.g. Chavez et al. 2015), does not seem relevant for ETO in established capital goods manufacturing.

We also note from the study that complexity and dynamism sub-factors related to regulatory requirements prevail in ETO mainly due to diversity and changes in the customer demographics rather than being imposed on the ETO firm’s operations. To be noted is that despite the limitation in information pertaining to secondary case, the spectrum of issues within the identified complexity and dynamism sub-factors appear to increase as one moves from mass customisation to complete Engineer-to-order as the primary and secondary cases indicate.

5.2 The moderation role of context factors

The second research question sought to understand how complexity and dynamism factors influence lean implementation strategy in ETO. The case analysis provides supporting qualitative evidence that these two context factors have strong influence on the way lean practices are implemented as well as subsequent performance gains.

To aid discussion on influence of context factors, we propose the framework depicted in Figure 2, where lean is represented with practice bundles (cf. Table 1). The arrows in the framework represent the possible influences of complexity and dynamism context factors on lean implementation strategy. Arrows B1 and B2 represent configuration role (i.e., they influence applicability of the lean practice bundles) further discussed in sec 5.3. Arrows A1 and A2 represent moderation role proposed in previous literature and discussed, for instance, by Azadegan et al. (2013). That is, they influence operations performance benefits of implemented practice bundles. For this empirical discussion only the primary case (AB) is used as the secondary case does not provide enough details in this regard.

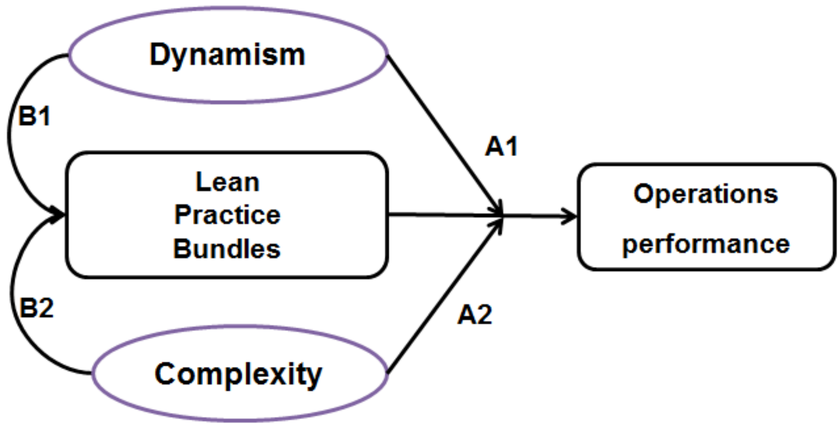

Figure 2. Configuration and moderation roles of complexity and dynamism in an ETO context

Evidence from the primary case regarding performance indicates that all the five objectives improved with the lean implementation (within less than two years of the initiative) in the prevalence of the highly uncertain internal and external context factors (cf. Table 5 column 4). However, the qualitative nature of the investigation did not enable us to differentiate the extent of moderation influence that each category of factors bears.

The performance improvements in AB imply that, the company could benefit from even better performance if lean practices were implemented to more processes in the value chain including engineering and design. It could have solved problems early on and protected them from passing along the interdependent processes. The achieved flexibilities in the shop floor, to better accommodate late change requests from customers (Gosling et al. 2015), could have been extended further by engaging more processes. Performance could be further enhanced with simplification of complex and interdependent processes as well as interaction through lean implementation (Marley and Ward 2013). Additional cost savings, quality improvements, learning opportunities and delivery of better service to customers (Radnor and Johnston 2013) are apparent from lean implementation in complex and dynamic ETO context as in AB.

Previous research focused mainly on the moderating influence of external complexity and dynamism factors on the lean-performance relationship (e.g. Azadegan et al. 2013; Browning and Heath 2009). Our investigation complements this by arguing that complexity and dynamism also include factors internal to the implementing firm. Consideration of the internal factors can provide additional opportunities of performance improvement and competitiveness for ETO firms in capital goods manufacturing.

The moderation effects of complexity and dynamism on the relation between lean practices and operational performance seem to be largely consistent with the findings of Azadegan et al. (2013). A possible difference is that the negative influence of dynamism on (internal) lean operations reported in Azadegan et al. (2013) may change with the segregation of influences into configuration and moderation as negative influences could be attributed to the configuration influences; this is particularly so with dynamism factor and the additional internal sub-factors extended in this study. These arguments however need to be validated with large scale study.

5.3 The configuration role of context factors

We mentioned that the configuration roles of complexity and dynamism ETO context factors (arrows B1 and B2 of Figure 2) are apparent from both the primary and secondary case studies. We did not find strong evidence to suggest that some lean practice bundle cannot be implemented in ETO just due to the prevalence of the complexity and dynamism factors. However, especially dynamism sub-factors seem to bear major challenge for implementation of at least some lean practices.

This was demonstrated by a quote from an informant manager in AB: '…*We had very tough period within September to December. The level of orders to be done, the turnover target to be reached, it was really crazy…at the moment all the lean activities have been stopped…*' Another manager also told us that during that period he had to tell employees in the shop floor to abandon activities like kitting due to the rush to meet annual turnover targets regardless of the positive prospects of lean implementation initiatives. It is also a big challenge to integrate and unify perception of diverse highly skilled workforce towards such change process as observed in AB. It was only after having recognised that not doing so only increases wasteful activities no matter how hard the employees worked that communication and inter-departmental understanding were improved. In HCC on the other hand, integrating R&D efforts with globally distributed integration partners, who also provide after-sales service, is a challenge.

At the same time, the context factors provide opportunities to experiment different ways of implementing relevant practices. For example, cycle time reduction (Seth and Gupta 2005) was thought to be a difficult practice to be implemented in ETO as products are different every time. We noted that both AB and HCC tried to address this issue by aggregating products into families and referring to experience on work packages to define and progressively improve cycle times at that level of aggregation.

HCC has noted that they had to deal with complexity arising from large number of suppliers and sub-contractors shared among multiple competitors (e.g. for tapered rollers) that contributed to late delivery times. This motivated them to continue their lean implementation efforts as they were able to bring those outsourced operations back to in-house and produce when the parts were required. This brought the benefit of reducing delivery times tremendously in addition to achieving better quality.

To sum, regardless of differences in implementation routines and path dependence in the change implementation processes among the case companies, the observations strengthen the configuration role proposed in our framework (Figure 2). Implementation of the lean practices in AB and HCC suggests that by furthering consistent exercise of the lean practices, ETO capital goods manufacturing firms benefit from structuring otherwise cumbersome activities as well as structured flexibilities that result as capacity is freed up from identified and removed wasteful activities.

6 Conclusions

Studies have shown that in repetitive manufacturing complexity and dynamism context factors have significant influence on the relationship between implemented lean practices and operations performance. This study investigated the uncertainty context factors in capital goods ETO manufacturing and their influence mechanisms on lean implementation strategy for which literature is limited.

With reference to the peculiarities of complexity and dynamism factors for ETO firms in capital goods manufacturing (RQ1), the study argues that most of the internal and external sub-factors related to both complexity and dynamism compiled from literature appear to apply to capital goods ETO with a few exceptions. They are: (1) Short average product life cycle is not an applicable complexity sub-factor for ETO; (2) Uncertainty in regulatory requirements exists mainly due to complexity and dynamism of the customer demographics in capital goods ETO; (3) with regard to the sub-factor "changes in mode of production", as it was reported in earlier literature, this study did not find enough evidence in the capital goods ETO.

As for RQ2, based on the empirical findings, we demonstrated the existence of configuration and moderation forms of influence from complexity and dynamism on lean implementation strategy in ETO. The moderation role of external complexity and dynamism factors on lean implementation has been addressed by previous research; the configuration role, and the moderation role of internal uncertainty factors have been proposed in this study based on empirical evidence. The implication is that we need to further investigate these different forms of influence to have a better picture of how high uncertainty context influences lean implementation strategy.

With analysis of ETO case companies, this study contributes to contingency theory in two ways. Firstly, it argues that complexity and dynamism factors constitute not only factors external to the business firm (e.g. Azadegan et al. 2013) but also factors internal and under the control of the organization. It also shows that some sub-factors of complexity and dynamism identified from repetitive manufacturing setting such as short product lifecycle (related to technological turbulence) and change in mode of production may not be so relevant and applicable for capital goods ETO.

Secondly, it discusses that the complexity and dynamism factors (both internal and external) have configuration and moderation roles of influence on lean implementation strategy. Configuration role of complexity and dynamism (with both internal and external sub-categories) has not been explicitly addressed in previous research. Moderation role of the internal complexity and dynamism factors is a contribution added by this study on the existing consideration of mainly the external uncertainty factors (e.g. Azadegan et al. 2013). By so doing the paper also adds to the limited literature discussing lean implementation in the ETO context. A framework of these two roles is proposed for further analysis with future research.

With the qualitative findings we forward the following arguments regarding the influences of uncertainty context factors in capital goods ETO on lean implementation strategy. (1) Complexity motivates lean implementation; (2) dynamism factors bear challenges to lean implementation leading to possible setbacks; (3) both complexity and dynamism appear to positively influence the lean-performance link.

From managerial perspective the study gives deeper insights on considerations of uncertainty factors in ETO, for such firms that want to implement lean. This is especially important for multinational ETO firms serving customers in diversified geographical and technical settings. Many European capital goods manufacturers that work in the same context as company AB does could make use of these insights. The paper also argues that complexity factors provide good opportunity to derive better value from processes, including remedies to combat challenges of dynamism factors. That means ETO managers' interest to implement lean in their high uncertainty context is well justified. Managers need to bear in mind the context differences and possible challenges in ETO in order to be benefit well from their lean implementations.

Current day businesses have to deal with different forms of uncertainty not particular to just ETO (e.g. unanticipated disruptions) (Craighead et al. 2007). From this consideration, it would be a point of future research to investigate whether structured approaches to operations risk management and resilience would complement lean implementation in ETO and other high uncertainty environments for better performance under unpredictable circumstances.

The study is not without limitations. The limited number of qualitative cases is a challenge for generalizability of configuration role from both complexity and dynamism factors. It cannot, for example, address for differences in the relative intensity of the context factors within the capital goods ETO. Large scale investigation is required to verify the proposed framework, and further analyse the configuration and moderation roles of the context factors on lean strategy with revised specification of the sub-factors in ETO environment. Another limitation of this study is unavailability of specific details to provide more elaborate discussion including influence of each sub-factor. We believe that an arrangement in an action research setting with the same or similar ETO context should provide much clearer insight about relationship of variables under consideration.

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Appendices

Appendix 1: Sample interview questions

1. Please tell us the roles and functions of your department
2. How do you describe lean implementation in your organization? What are the benefits you got and challenges faced?
3. Why is lean implementation important to you?
4. How do you motivate your employees to do what they have to when it comes to improvement initiatives with the lean implementation?
5. How do you relate your lean implementation with your goals and annual performance targets?
6. What is the role of your parent company in the production management, setting targets, or lean implementation process?
7. How do you describe the relationship and communication with your customers and suppliers? How would you characterise your customers?
8. Please describe features of your products (e.g. how similar they are from one order to another). How is your ETO business different from, say, mass production?
9. What performance indicators do you use to evaluate your department’s work?
10. What is your strategy about inventory keeping and capacity utilization levels?
11. How does your lean implementation coordinate with outsourced work?
12. Can you describe for us example of a typically problematic project and how you addressed the challenges faced?
13. If you did not have any resource limitations in the organization, what would have been your biggest challenge from outside of your organization?

Appendix 2: Qualitative lean practice implementation scores

Bundles	Underlying practices assessed	Indicative implementation level for: High, Medium, Low
Total quality management and visual management	Quality management programs Formal continuous improvement programs Process capability measurement Use of proper visual tools	If visual concepts, SPC, and quality management programs are understood and practiced extensively, the score is HIGH. If the concepts are understood, but have limited application, the score is MEDIUM. LOW, otherwise.
Just-in-time/ Flow	Cellular layout Bottleneck identification and removal Cycle time reduction Reengineering processes Quick changeover techniques	If there is an aggressive program to reengineer processes, establish cellular layout, identify bottlenecks, reduce setup times and cycle times in all operating areas, with a visible improving trend, the score is HIGH. If only some operating areas have such programs and these show an improving trend, the score is MEDIUM. LOW, otherwise.
Human resources management for lean	Job rotation, design, and enrichment Formal cross-training programs Problem solving groups and employee involvement Flexible cross-functional work force	If plans to establish necessary teams, to identify and perform ongoing cross-training, and job enrichment exist and are exercised extensively, the score is HIGH. If the practices are occasional, but not as part of an overall plan, the score is MEDIUM. LOW, otherwise.
Lean purchasing	Reduced purchase order sizes Short order placement processes Reduced need for incoming material inspection	If arrangements are in place to reduce the need for lengthy purchase order placement (for parts and outsourced work), order size reduction to purchase only items confirmed in customer order, the score is HIGH. If there are only some sporadic initiatives with regard to these practices the score is MEDIUM. Low, otherwise.
Customer involvement and partnership	Customers’ direct engagement in product offerings Customers’ feedback on different performances	If customers are routinely engaged in aligning their requirements with products being developed and manufactured as and if they provide feedbacks based on which improvement action is taken, the score is HIGH. If customer engagement is there with the feedback for improvement collected but limited action is taken, the score is MEDIUM. LOW, otherwise.
Supplier involvement and development	Close contact and long term relationship Supplier development and certification Improvement commitments from suppliers	If programs are in place, and result in long-term relationships being established with key suppliers based on their ability to meet manufacturing needs (e.g. cost, quality, and lead time), the score is HIGH. If limited key supplier programs are in place, and some key supplies are purchased with negotiations focused on only price, the score is MEDIUM. LOW, otherwise.
Standardisat-ion	Standardising processes and procedures	If evidence exists on the creation and the uses of formal documentation and procedures to drive consistent work, the score is HIGH. If there are set procedures only for part of the work or if not formally used in all concerned units, the score is MEDIUM. LOW, otherwise.
Total productive maintenance	Maintenance optimisation techniques Preventive/predictive maintenance techniques New process/technology acquisition	If there is a defined education, training and implementation program for TPM concepts, and evidence show broad application and results, the score is HIGH. If there is a defined program, but application is limited in scope, the score is MEDIUM. LOW, otherwise.