Sustaining performance under operational turbulence: the role of lean in engineer-to-order operations

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Abstract

Purpose: Many studies have found out that lean practices provide better performance in a stable business environment. However, there is limited information on how lean practices influence performance gains (defined in this paper as improvement and sustenance of performance) in uncertain (complex and dynamic) environment. This study investigates how the implementation of lean helps to sustain performance in such context.

Design/methodology/approach: The study draws on an in-depth investigation of two capital goods manufacturing engineer-to-order (ETO) cases in which performance sustenance is discussed in relation to the extent, locus, and extensiveness of implemented lean practice bundles.

Findings: Findings indicate that a higher extent of lean practices implementation, covering both shop floor and transactional processes increases the possibility of performance sustenance in ETO. Furthermore, coherent approach in the pre-, during-, and post-implementation phases of the lean change process are required to foster performance sustenance. Lean practices in ETO are modified to suit context change from repetitive manufacturing.

Research limitations/implications: This study proposes performance sustenance as a performance measure in highly uncertain context, such as ETO, as a single reference cannot effectively measure performance improvements over diverse orders. From this perspective, appropriate lean implementation contributes to build capabilities for flexibly and proactively managing uncertain circumstances.

Practical Implication: Even companies operating in highly uncertain (complex and dynamic) contexts may benefit of significant performance gains thanks to lean implementation. It can be achieved by a balanced implementation of practices at shop floor and transactional processes, and their mindful customisation.

Originality/value: The study compares lean implementation in ETO with that of high-volume-low-variety systems established in literature. It qualitatively discusses how lean implementation as an overarching effort both in shop floor and transactional processes leads to a better sustenance of achieved performance improvements in shop floor under high uncertainty.
Keywords: case study, engineer-to-order, lean production, performance improvement, uncertainty

Article classification: Research paper

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Introduction

It is widely documented that implementation of lean practices leads to performance improvements (Liker, 2004; Shah and Ward, 2003; Womack and Jones, 2003). However, some researchers question the extent of lean's applicability in non-repetitive production situations (Cooney, 2002; Naim and Gosling, 2011), such as engineer-to-order (ETO). However, there are several challenges that motivated ETO companies to implement lean amid prevailing uncertainties (i.e. complexity and dynamism). Recent literature is capturing this evolution (e.g. Powell and Stoel, 2017). These companies are constantly pushed to fulfilling the specific requirements of customers flexibly in shorter lead times to remain competitive (Zorzini et al., 2008). In addition, customers in ETO require their late change requests be complied with. Under the current tightening economic conditions, improving cost efficiency is important for high variety low volume manufacturing.

ETO refers to a supply chain structure or a set of strategies followed in manufacturing operations (e.g. Chen, 2006). The ETO product development process starts with customer requests and specifications for each order and usually ends with an engineering design or manufacturing, assembly and delivery of the designed items (Chen, 2006). Typical features of the customised products are defined through on-going negotiations (Gosling and Naim, 2009) and usually involve long cumulative lead times from order placement to shipment. Given its peculiar organisational and operational arrangements, the ETO environment is characterised by high complexity and high dynamism. Briefly stated, complexity refers to the level of heterogeneity (i.e. a large number of dissimilar factors affecting decision making), whereas dynamism is related to unpredictability and the absence of patterns, that is, decision making factors continuously change over time (Duncan, 1972).

Increased uncertainty in terms of complexity appears to have further facilitated performance improvement benefits from lean implementation (Azadegan et al., 2013). Nevertheless, the empirical evidences provided by researchers are mainly based on repetitive manufacturing where uncertainties are relatively limited. However, it is reported that there are opportunities for operations performance gains through lean implementation in an ETO context (Birkie and Trucco, 2016; Powell and Stoel, 2017) which represents highly complex and dynamic environment.

In this regard, measurement of performance gains is not always easy in ETO manufacturing because a single reference may not be valid for comparing the diversified orders. Therefore, a more comprehensive way of measuring performance gains is required. In this study, we argue that in ETO firms keeping up improvements over diverse orders and order mixes (shortly referred to as performance sustenance in the following paragraphs) is an equally important element for a thorough evaluation of lean implementation benefits on operations performance.

However, lean implementation and subsequent performance gains (especially performance sustenance) in such context are not well addressed in the extant literature (e.g. Portioli Staudacher and Tantardini, 2012). Accordingly, this study intends to analyse how customised lean implementation in high complexity and high dynamism ETO environment is, if at all. The paper also intends to explore, in the same environment, the influence of lean implementation on performance sustenance. Therefore, this paper aims to answer the following research questions.

RQ1: How does lean practices implementation in ETO capital goods manufacturing compare to widely established literature of lean in repetitive manufacturing?

RQ2: What is the influence of lean implementation on performance sustenance in ETO capital goods manufacturing firms?

Answering these research questions is important for several reasons. First, since only few studies have addressed the specific requirements that might exist in ETO with regard to lean implementation (e.g. Powell and Stoel, 2017), such a kind of study is expected to contribute at solving the current contradictory perspectives among scholars on lean implementation beyond repetitive operations. Second, by developing knowledge about these specific conditions, managers in ETO could make more informed decisions about how lean could be successfully implemented. Third, a better knowledge about lean implementation in highly dynamic and complex environments, such as ETO, has also implications for lean implementation in general as the global business climate is experiencing disruptions and increasingly uncertain internal and external conditions.

The remainder of this paper is organised as follows. Section two is a brief literature review of lean and its implementation in the context of ETO. Section three describes the multiple case study methodology adopted. Sections four and five respectively present and discuss the findings regarding lean practices implementation, as well as performance gains in the case companies. Finally, in section six, we draw conclusions from the study and highlight implications for practice, theory, and further research.

Literature review

Lean practice bundles

According to Shah and Ward (2007), lean production is an integrated socio-technical system whose main objective is to eliminate waste by concurrently reducing supplier, customer, and internal variability. The guiding principles of lean are described as a focus on people, a value driven process view, problem solving, and long term thinking (Liker, 2004; Womack and Jones, 2003) which are translated into observable practices.

These lean practices are diverse and often grouped into practice bundles. Simply stated, bundles refer to categories of consistent and logically interrelated practices (Shah and Ward, 2003) 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 bundles that focus on internal processes. Practice bundles which focus on "external connections" include the active involvement of customers, collaboration, and long term relationship with suppliers (Azadegan et al., 2013; Shah and Ward, 2007). Having considered relevant literature, we characterise lean as a socio-technical management system consisting of eight practice bundles, namely: (1) *total quality management and visual management;* (2) *just-in-time/flow*; *(3) human resources management*, *(4) lean purchasing*, *(5) customer involvement and partnership; (6) supplier involvement and development; (7) standardisation*; and *(8) total productive maintenance.* List of practices belonging to each bundle can be found in Birkie and Trucco (2016). Interested readers may additionally refer to Bortolotti *et al.* (2015) for a detailed list of literature on lean bundles and underlying practices.

Traditionally, the emphasis of lean implementation has been directed to the manufacturing shop floor. This is evident by the extensive research and practitioner literature that predominantly discusses shop floor practices and associated performance improvements. However, the synergetic effects of implementing such practices within and outside the manufacturing shop floor has also been highlighted in past research (Scherrer-Rathje et al., 2009; Shah and Ward, 2003). A recent empirical investigation by Fullerton *et al.*, (2014) argues that lean has to be adopted as a holistic business strategy across shop floor and other (transactional) business processes of the enterprise in order to enhance operations performance.

Lean practices implemented in ETO can be described with regard to locus of implementation in the organisation, such as the shop floor or transactional processes (Nash and Poling, 2008). Transactional processes are processes that do not involve direct manufacturing or production, but instead involve interactions and communications between different units (within or beyond the enterprise), also to support the manufacturing operations; thus, they directly contribute to creating value for the client. In transactional processes, the main flow is that of information, and the output delivered is often paperwork, e.g. reports, purchase orders, services delivered, etc. (Nash and Poling, 2008).

The aforementioned lean bundles encompass practices that may be implemented on the shop floor or in the transactional processes. For example, cellular layout, quick changeover techniques and bottleneck identification of the JIT/Flow bundle, as well as most of the total productive maintenance (TPM) practices are often associated with the shop floor processes. Lean purchasing (LP) practices are mostly concerned with transactional processes. Some other practices, such as direct customer engagement and supplier development, may transcend transactional and shop floor processes.

Companies implementing lean tend to show better performance when lean practices are implemented in shop floor (manufacturing) as well as transactional processes (Sisson and Elshennawy, 2015). Such firms also tend to have policies and integration activities across functions that support their lean goals- a process called *hoshin kanri* in Japanese. However, large number of publications on lean dominantly discussed lean practices and performance benefits only at the shop floor level (e.g. Raghavan et al., 2014). This is possibly because the process of extending lean implementation to extended organisation is difficult and haphazard despite the gains (Cudney and Elrod, 2011).

Lean practices employed in ETO environment can be evaluated in terms of *fidelity* and *extensiveness* relative to the forms adopted in repetitive manufacturing as suggested by Ansari et al. for diffusion of innovative practices (Ansari et al., 2010). *Fidelity* refers to the in-kind resemblance of the adopted practices to the features of previous version of practices (Ansari et al., 2010); that is, if the practices are implemented according to the state-of-the-art. *Extensiveness* refers to the degree or extent of implementation of the practice, compared to that of a previous version. In this study, we use these three aspects (locus, fidelity, extensiveness) to understand implementation and implication of lean in ETO.

Lean implementation framework

Bhamu and Sangwan (Bhamu and Sangwan, 2014) argue that there was lack of a standard framework for implementing lean, and propose one in their paper. According to them, there are three phases of the lean implementation: *pre*-, *during*-, and *post-implementation*. The framework suggests that effectiveness of lean implementation depends on the initiatives and practices exercised in each phase.

The pre-implementation phase is concerned with creating good understanding of lean among all relevant stakeholders. Employees at different level are expected to have active involvement in the change process that they need to be convinced of the idea. Lack of this may result in (improper) implementation with wrong operational details (e.g. Langstrand and Drotz, 2015). Top management’s commitment to plan and alleviate barriers (Jadhav et al., 2014) of implementation to improve performance gains from lean efforts is pivotal (Bhamu and Sangwan, 2014). During the implementation phase lean practices are implemented in the planned scope so as to get performance benefits from all the activities in the value chain (Hines et al., 2004; Womack and Jones, 2003). The post-implementation phase is about evaluation and continuous improvement, to benefit even better by considering all the value chain processes. However, localised improvements could limit this (Bhamu and Sangwan, 2014).

The framework proposed by Bhamu and Sangwan (Bhamu and Sangwan, 2014) can be used to map lean practice bundles and depict differences in the implementation approach (if there are any) when observed in different contexts (i.e. ETO versus repetitive manufacturing environments). This can be done along with the evaluation of fidelity, extensiveness, and locus of the practices implemented, as already pointed out.

Research methodology

Approach

Case study research approach was used in this paper as it provides better internal validity through close observation of the phenomenon of interest in the natural context (Eisenhardt, 1989; Yin, 2003). As the topic of implementing lean in ETO is relatively unexplored, case study approach has been found appropriate in similar recent studies (e.g. Matt and Rauch, 2014). The steps suggested for theory building case (Eisenhardt, 1989) were followed. For instance, research questions were defined considering lean practice bundles set *a priori* based on extant literature (e.g. Birkie and Trucco, 2016; Bortolotti et al., 2015; Shah and Ward, 2003); we studied the cases considering the business units with ETO operations as our unit of analysis. We observed and collected data from the different value chain processes of the business unit. The ETO cases were selected based on the objective and research questions set. They were relevant for the study because they: (1) had the willingness and resources to implement lean, and (2) provide possibility to observe how an ETO business inherits or integrates lean culture with repetitive manufacturing units under the same corporate management. However, we had to limit the cases to only two due to resource limitations. Multiple data collection methods, including interviews with follow up sessions, shop floor visits, and company documentation were used for triangulation (Yin, 2003).

Empirical case setting

The two case companies are the Italian branches of multi-national companies and both use an ETO mode of manufacturing. Case A refers to an ETO firm that is part of a large multinational group with 65 manufacturing locations globally. The company has been implementing lean in this specific business unit for about five years. The parent company, however, has been implementing lean for more than a decade in its mostly repetitive manufacturing setting.

Case company B is a company with ETO operations that produces diverse specialty and heavy duty pumps, valves, and other flow control devices. The products are sold in more than 70 countries to customers in oil and gas, power generation, and other process industry fields. The company has been implementing lean for about 15 years with increasing span of application. Table 1 provides summary of description of the case companies A and B.

Table 1. Brief description of the case companies

	Case A	Case B
Major product lines	Hydraulic power units, control units, manifolds	Pumps, valves, other flow control devices
Turnover of the studied branch (2013)	1.96 Billion Euros	240 Million Euros
Number of employees	450	500
Main markets	Asia-Pacific, Europe, Americas	Middle East, Europe, Americas
Lean implementation duration at Group level	10+ years	10+ years

Case companies A and B provide comparable cultural setting to enable logical comparison of extent, locus and fidelity of lean practices implementation. Table 2 provides a brief description of some cultural elements in the two investigated cases.

Table 2. Similarity of organisational context issues in the case companies

Parameter	Case A	Case B
Investigated unit/plant	Italian Plant of a multinational firm	Italian Plant of a multinational firm
Sources of strategic components	Supplied by sister plants of the same parent company	Supplied by plants of the parent group in other countries
Feature of market localisation	Part of multinational business with market of the investigated plant focused on local direct customers (who may have sites or customers elsewhere in the world)	Same
Management style	Claimed to be “German” style but local way of doing business dominant	Claimed to be “American” style but local way of doing business dominant
Existence of enabling cultural change	Attempts made (and succeeded) to change cultural and organisational elements to enable smoother understanding and implementation of lean	Pre-implementation trainings and braining storming with changes in roles of team leaders made at the beginning (though these enforcements did not continue throughout and longer)
Resistance/challenge on implementation	The form of resistance on lean implementation faced by workers in these two firms were similar. Common observed conditions: the presence of lean consultants and leaders was perceived as “job performance monitoring” rather than directed to supporting process improvement; misalignment of compensation schemes and lean goals; changing focus on dealing with turnover and increased orders as a reason to abandon implemented practices.	

Data collection and analysis

Our investigation was carried out sequentially with company A being studied first. Multiple sessions of semi-structured interviews, long hours of shop floor tours, and a review of company documentation including annual reports were used as data sources for confirmation, completion and triangulation of data obtained from different sources.

In case company A, we had a total of nine hours of interview in 6 sessions with 5 informants from production planning, procurement, quality management, and engineering functions. We had two visits to the production shop floor each half a day long. One of the authors has also participated in one multi-functional Kaizen meeting and multiple brainstorming sessions in the organisation to have a closer observation of how their lean implementation worked. More than 60 pages of extracts from the company database, reports from the lean consultants, and on-going performance evaluations in the case company were also reviewed.

The experience obtained in the investigation of case company A was used to run interviews in case company B more efficiently. This was done by sending out structured questions prior to the meetings. Six hours of interview has been conducted with the plant manager at the site investigated. Four hours of focused interview in two sessions was conducted afterwards with the director of operations strategy of company B, and responsible for lean implementation at group level. During follow-up sessions, the informant reviewed synthesis of the interview as a way of triangulation. Two plant visits, each half a daylong, were conducted in the office and shop floor as well. Furthermore, one of the research groups involved in the present study had a longstanding collaboration on several projects at company B connected to lean implementation and performance improvement (e.g. performance analysis of shop floor activities performed by people with disabilities, and shop floor re-layout and Kaizen).

We had full access to different technical reports from such pilot projects and were able to recall and extract relevant data with a good level of detail.

To assess lean implementation extensiveness, we used the scoring approach developed by Birkie and Trucco (2016). Similar examples of such scoring for lean practices can be found in different literature (e.g. Nightingale and Mize, 2002). Accordingly, three scoring levels – low (L), medium (M), and high (H) - map the extent of implementation of lean practices based on the interviews, documentation and direct observation. The description of these levels was developed in order to consistently assign scores to the practices. Low represents limited/sporadic application of a practice; medium level implies that the practice has been employed to some extent or only in a few of the several possible areas; and high signifies consistent implementation with a good level of understanding of benefits and challenges.

As an example, the use of multi-functional teams on the shop floor of A was classified as low because there were no incentive structures and designed training programmes that could enable such initiatives. The claimed multi-functionalities were limited to very similar functional areas or to additional tasks that do not normally require extended efforts of learning and practice. The multi-functionality of employees in case B is supported with an enabling employee promotion structure. So, it was awarded a medium score. It was not a high because there were some employees that were not yet multi-functional, and the company was still striving to achieve an even higher number of multi-functional employees. All other practices were graded low, medium, or high in a similar fashion.

Findings

The lean practices implemented in cases A and B were classified according to the set of lean bundles and the lean implementation framework (Bhamu and Sangwan, 2014).

They were further summarised into practices implemented in shop floor and transactional processes (locus), fidelity, and extensiveness as shown in Table 3.

Lean implementation in cases A and B

In general, practices from each of the representative lean bundles have been implemented in both case companies. Both companies A and B implemented multiple practices from most of the eight lean bundles; not all practices in each bundle were implemented though. For example, in company A, only eight practices belonging to three bundles were implemented in transactional processes whereas in company B, 21 lean practices covering 6 bundles have been implemented as shown in Table 3. The number of practices implemented and bundles covered in the shop floor processes in both companies appears to be comparable.

Both case companies had strong lean implementation in the production shop floor; they both extended implementation starting small there and extending across multiple processes in the value chain. The extensiveness of implemented practices is different in the two cases. The number of practices increases as we move from high extensiveness to low in case company B; the trend is reversed in case of A. When it comes to fidelity, the implemented practices very much resemble those implemented in repetitive manufacturing. Some peculiarities exist, however, to accommodate differences in the specific business nature of ETO in capital goods sector. These customisations are better described in the subsequent section.

Table 3. Summary of findings based on proposed framework

	Case A	Case B	Remark
a) Locus	• 8 lean practices belonging to 3 bundles implemented in transactional processes • 21 lean practices belonging to 6 bundles implemented in shop floor processes	• 21 lean practices belonging to 6 bundles implemented in transactional processes • 17 lean practices belonging to 5 bundles implemented in shop floor processes	• Case B is better in implementing diverse practices in transactional processes; whereas case A is better in shop floor practices implementation
b) Fidelity	• Practices from all bundles implemented somehow	• Equal or higher number of practices per bundle implemented compared to case A	• Case B has marginally better implementation of JIT practices; types of practices vary a little
c) Extensiveness	• Implementation of practices ranges from low (16 practices), medium (6 practices) and high (5 practices)	• Implementation of practices ranges from low (13 practices), medium (20 practices) and high (15 practices)	• Case B has a higher number of practices extensively implemented
d) Implementation phase	• The implemented practices in the pre-, during-, and post- lean implementation phases respectively are: 9, 16, and 4	• The implemented practices in the pre-, during-, and post- lean implementation phases respectively are: 19, 15, and 6	• Case B has more practices in earlier phases of implementation

Lean implementation in case A

We learned from case A that they had some level of pre-implementation planning (but lower than that of B) and awareness creation about their lean implementation (see last row of Table 3). For example, relevant roles to drive the lean journey were created;

standard shop floor workstation elements were set, and quality gates were established.

Communication problems led to some challenges during implementation phase in company A. They also faced challenges to the lean change process with growing order sizes in addition to order diversity that made lean efforts more difficult compared to just volume changes in repetitive manufacturing. One of the informants from company A told us that they received pre-sorted materials for each job directly from the warehouse. *"At the beginning, we had a lot of benefits from this"*, he says, *"In the last period, when everything was growing and growing, we again had problems due to missing materials…"* The root causes of many of the problems identified during the lean implementation at shop floor level (e.g. in investigating why an order was too late) point to problems in the transactional processes.

We also observed that the number of problems solved compared to the number identified in a week was at times as low as -27% after having achieved much higher values. Localised improvements in case A seem to have limited the possibility to continue improvements and gain higher benefits from lean implementation (Bhamu and Sangwan, 2014). The efforts during pre-implementation do not seem to be enough in addressing the high uncertainties of the ETO context.

Company A's managers and lean facilitators were convinced that further performance benefits could be achieved in all processes. However, these benefits were not fully realised as the implementation was not integrated in addressing all the value chain processes, especially for transactional ones. In fact, the performance gains in production shop floor have been lost due to wastages in some "non-lean" activities. For example, the lead times in the assembly processes were shortened considerably; however, missing information or parts could not enable achievement of final delivery by agreed due dates. The resistance from some divisions due to conflicting interests

(Jadhav et al., 2014), not directly related to lean implementation, played its part too. The sales personnel, for example, were mainly interested in how many orders they brought, no matter how late the orders might be delivered possibly because of misinformation or capacity utilisation levels not considered in dealing with customers.

Lean implementation in case B

Company B's commitment for lean implementation is partly reflected in the restructuring of its organisation and work environment before commencing on the lean journey (e.g. manufacturing cells and front line office). It also established a customised remuneration scheme to reward the lean efforts that accommodated national payment regulations (which were considered as barriers). In line with this, we also noted that company B had more practices at pre-implementation phase.

Despite the good pre-planning, the lean implementation in company B was not without challenges. The informants explained to us how very strong their JIT approach was. However, as their JIT culture had somehow declined to a "hybrid form" over the years. A significant increase in the volume of orders was a challenge for lean implementation in ETO. An informant at company B expressed this by saying:

> *At that time, we were very strong in the JIT. … [This concept was] a little bit lost because of […] very huge volume with a lot of problems with the suppliers who were not able to perform at the same level of high performances because of the volume, because of the [in]complete activities and so on…*

However, the company managed to smoothly extend the implementation of the practices in multiple functions and processes of the organisation that helped to enjoy improvements across multiple functions. The kinds of challenges faced by company A (e.g. changing performance targets) were fewer in company B as the lean vision had been set at the outset and its benefits had been made visible to corporate management.

A combination of the incentive schemes, changes to shop floor layouts and organisational rearrangements must have contributed for the relatively smoother continuation of the implementation process. We observed in the company that they continued to regularly evaluate and retain achieved performance while striving to attain further improvements.

The total number of lean practices (i.e. 38 practices) as well as the extent of implementation in case company B was higher than that of A; most practices had medium or high extent of implementation (see Table 3).

An interesting observation in case company B, in relation to their lean implementation, is the project with which they brought in people with mental disabilities, and trained them to carry out assembly operations. This project helped improve and simplify shop floor processes. A manager explained the situation like this:

> *[The] disabled were actually responsible for the assembly of the bearing housing […] These are very attractive lean projects because when you work with the disabled, you must be focused on their characteristics and you have to re-build your process to be really simple without wasting anything, because [otherwise] it is difficult to teach the disabled to make just what you need.*

Out of the 38 practices implemented in company B, 21 were focused on transactional processes while the other 17 were shop floor based. The company also has a front-line unit that was aware of the whole process including technical details. This has reduced the need for passing excessive paper work to different functions. At least 10 of the 21 lean practices in transactional processes were observed in the front-line unit.

Customisations of lean practices in ETO setting

Some of the lean practices in ETO setting have been implemented in customised forms. We observed that companies A and B employed customisations to eight and eleven unique lean practices respectively.

Several customisations were supportive of customisations in other practices. For example, company B had price negotiation with suppliers based on catalogue of product families. This enhanced several lean practices such as reducing purchase size per single order, and simplifying order placement burden, while economies of scale were retained. The informant in company B mentioned that working with the suppliers as partners gave them the capability to negotiate prices at aggregate levels regardless of diversity so as not to penalise the economies of scale. He states:

> *If you negotiate every time [you purchase] you are making waste…knowing the costs and margins of our suppliers, if we need a reduction in price we work together on the cost side to make modifications…in this case you can achieve good results also without large volumes or negotiating at every step.*

The reduced lead time obtained also allows having multiple customer design change freezing points. He describes why this is so: "*In our market, customers order pumps, and two months after the order, they ask for a modification*" and this demands flexibility. "*In order to be flexible, you must have a very good lead time capability*", he adds. The multifunctional employees on the shop floor are a source for flexible manufacturing capability too.

This enabled the supplier make deliveries directly to the shop floor (kitting area), eliminating the unnecessary movement of items in cartons and pallets to and from warehouses. So, instead of the buying ETO firm sending frequent request for parts, the supplier of common parts regularly checks the inventory at the buyer's shop floor.

Close contact and long term relation with suppliers in company A was employed such that key suppliers (i.e. sub-contractors) would display their production plans in company A's shop floor that the assemblers would know when to expect the parts for specific orders. The engineers in company A were encouraged to engage in problem solving through reduction of inventory already in stock (accumulated due to long delivery lead time, or unused due to late changes in previous customer orders) using their engineering skills to utilise those available items. This also meant possible reduction in delays to wait for new purchases. Likewise, the reorganisation and business process reengineering, making the frontline unit responsible for the end-to-end process, significantly reduced the paper work and information loss that would have otherwise been big limitations.

Visual tools (i.e. floor markings in kitting area) in the shop floor have been evidently used as information Kanbans in addition to their immediate benefit of enhancing flow, job rotation, and proper capacity utilisation. This was strongly implemented as customised approach in company B, while company A went some steps in that direction.

Another customisation observed in the two cases is that engineering and design function is made part of the focus in standardisation. This included procedures for updating order details and moving references as changes occur at different stages of the order processing.

Performance gains in the case companies

Brief comparison of operations performance improvements due to the lean practices implementation in the two case companies is presented in Table 4. For example, Company A was able to improve on-time delivery from an average of 57% to 80% during the period covered by this study. Company B improved on time delivery manufacturing from 75% to 93%, and after sales service to 98.5%.

In company A, products delivered with a delay of more than 20 working days accounted for about 35% of total deliveries prior to lean implementation; this value reduced to nearly zero afterwards. However, this gain began to quickly erode in the rush to meet annual corporate revenue targets. The large number of orders “pushed” through the system to meet that target was clearly giving rise to more and more mistakes and wasteful activities, with negative consequences on the on-time delivery performance.

Both firms did not explicitly provide quality improvement data. However, passing incomplete or wrong information along the different project stages was a top problem in case A, as it was mentioned by almost all the informants. Cost measurements were not clearly observable though the company claimed that purchasing-based cost savings were achieved.

Both firms claimed that they wanted to improve flexibility to better address customer requirements amid complexities and dynamism in the business environment. However, it was rarely well defined how flexibility is evaluated in the two case companies. When we asked how they would describe their achievements in flexibility, they often referred (back) to other metrics like cycle- and lead-time reduction to better accommodate uncertainties. From our qualitative data, it is only possible to discuss flexibility capabilities the firms possess to face the dynamism and uncertainties in dealing with their customers.

Table 4. Performance improvements in the two case companies

Case company A	Case company B
1. *On-time delivery* improved from about 57% to well above the 80% target set (but not sustained) 2. Production *due dates* improved even with late start of assembly (localised gains); Potential benefit on aggregate *lead time* reduction 3. Directing flexibilities to provide better dependability for customers 4. Lower *cost* of manufacturing with higher flexibility (internal inefficiencies are still challenging), cost reduction in relation to purchasing process (achieved performance improvements need to be estimated in a better way) 5. Potential for *quality improvement* exist but process-based first pass quality at all stages is still a challenge	1. *On-time delivery* performance (customer service) was 75%. Now it is 98.5% for the aftermarket, and 93% for original equipment manufacturing with the shorter lead times 2. Average *lead time* improved from 60 weeks for all products to a current value of between 36 and 44 for the two different product families. 3. The company was expecting a 50% *cost* reduction, the actual result was 30-35% because 15% of the cost was absorbed by re-organisation and related efforts 4. Flexibilities to accommodate late customer change requests 5. The *process improvements* enabled for sustaining high quality (cost of poor quality 1.02% of sales);

In company A most of the realised capabilities for flexibility remained on the shop floor and were dominantly focused on manufacturing activities. The lead times of assembly and testing operations were very short in relation to the overall cycle time, and were used to help make adjustments on sequencing and adjusting start time for the assembly process. As long as all necessary inputs were available, production could be finished within the planned timeframe. The problem was that capabilities that enabled flexibility on the shop floor were not extended to the overall order fulfilment cycle. As mentioned earlier, the company outsourced many operations, and this activity was considered as a source of flexibility, even though it was not well utilised due to limitations within the transactional processes that could have exploited it.

We have seen a strategic approach to creating capabilities that increased flexibility needed to be able to consistently provide high customer satisfaction in case B. The operations strategy manager stated that they re-utilised the capacity freed as a result of different improvements to foster their flexibilities.

The informant in case company B also mentioned how customer requirements shifted from asking for “pump pressure” and “flow capacity” values to selection of specific components in a holistic system. He clearly pointed out that the capability to address changes flexibly is required in order not to lose sales of strategic competence to customers. Referring to the stressfully dynamic nature of changes in the market requirements, the informant at company B said “*We need to again be more flexible when we try to follow these new rules of the market*”.

The frontline unit deals with most transactional processes with seamless handling of issues throughout the value-stream phases. This helped revealing opportunities that can be utilised also in the after-market service, for example, by reducing warrantee costs.

Discussion

The ETO environment is characterised by high complexity and dynamism. The first research question in this study seeks to explore if lean in such context is any different from repetitive manufacturing sector. The second research question addresses the influence that ETO context characteristics (i.e. complexity and dynamism) might have on the performance gains brought by lean implementation (Azadegan et al., 2013; Browning and Heath, 2009). These points are widely discussed in subsequent sub-sections.

Peculiarities of lean implementation in ETO: customisations that work

Bortolotti *et al.* (2015) found that technical and analytical (or “hard”) elements mainly exercised on the shop floor need to be complemented by people-focused (or “soft”) lean practices along the value chain in order for the lean implementation to succeed. This is particularly important for the complex and dynamic context of ETO as successful lean implementation has to ultimately sustain performance and keep up incremental improvements despite prevailing uncertainties. Matt and Rauch (2014) argue that while some lean “methods” appear more appropriate than others in ETO setting, the core issue for a continued implementation and long lasting performance benefit is the mind-set of the employees in embracing the change.

Most of the lean practices implemented on the shop floor processes in cases A and B appear to be very similar in terms of variety (Table 3). That is, the two companies implemented almost the same “range” of practices, even though that of B seems slightly broader. However, the extent and persistence of implementation differ substantially. To mention a more specific difference, Matt and Rauch (2014) found that use of Kanban appears to be less suitable in ETO. However, as we have observed in company A, the Kanban cards can be customised to suit and provide information specific to the different orders. Likewise, we have seen multiple customisations in both companies. This generally implies that even seemingly less suitable practices could be customised to address high variety and less predictable context.

The customisations employed in the ETO case companies seem to enhance the performance sustenance as they help to keep diversity of orders in check. Moving references frequent updates meant more iterations of learning in ETO setting. Most of the customisations were geared towards leveraging the diversification in customer orders and utilising multiple practices in integration. The collective efforts in the customisation of practices, when properly done, were positively influencing the chances that orders are timely delivered at reduced costs with even better flexibility to accommodate late changes.

According to contingency theory, it is expected that the implementation solution of lean systems could follow customised approaches that practically create differences as well as competitive leverages to suit a specific context. In the case companies, we did not find particular lean practices implemented that seemed to be “misaligned” with the highly complex and dynamic business context of ETO capital goods manufacturing. What we have observed is a mindful customised implementation of the practices in the different phases to suit prevailing circumstances.

We learned from the cases that the implemented practices were beneficial for the betterment of operations performance (no matter how small or short term). This is in line with several studies that have found a positive link between lean practices in a company and improvements in operations performance (e.g. Chavez et al., 2015; Shah and Ward, 2003). We therefore argue that all the practice bundles discussed in this paper seem to be relevant for environments of high complexity and dynamism such as ETO capital goods manufacturing.

The level of resistance to implementing lean practices in transactional processes in case company A was much stronger than in B. This kind of resistance and tendency to revert to pre-lean habits is however not uncommon in lean implementation change projects (e.g. Scherrer-Rathje et al., 2009), especially when a clear lean vision and an understanding of the overarching performance benefits are lacking. At some moments company A had to abandon lean initiatives due to corporate level target changes they had to adhere to.

Previous studies have shown that companies with more extensive implementation of lean got better performance gains compared to those with lower level of “leanness” under the same context (e.g. Chavez et al., 2015; Shah and Ward, 2003). The extent of lean practices implementation in the two case companies is clearly different. We have seen that company A has lesser extensiveness of most practices compared to that of company B. This, together with differences in locus of lean implementation (i.e. more practices in transactional processes in addition to shop floor) seems to have facilitated better performance sustenance in company B.

Sustaining performance with lean implementation

The performance gains obtained through lean practices implementation in the two case companies were different. Company A had more difficulty in sustaining the performance with the lean implementation. The implementation of more lean practices in transactional processes, and the higher extent of implementation in case company B must have some bearing on the differences in performance sustenance as well as improvement. Types of lean practices (and practice bundles) appear similar in the two firms that we do not see any contribution of the small differences in fidelity to explain the observed differences in performance gains.

In case company A, lean practices implemented in the shop floor processes helped attain some improvement in operations performance. However, this strategy alone was not sufficient to leverage for sustaining performance given the influence of environmental uncertainty (dynamism and complexity) as the application of lean practices in transactional processes is very limited. In fact, the gains may be lost due to rigidities that emanate from elsewhere in the organisation. These rigidities could have led to lean fatigue and performance fall-backs or even to abandoning of practices when unexpected rapidly changing operational turbulences occur (e.g. the headquarter pressure to meet the annual budget target). Implementing lean without aligning organisational arrangements with the intended goal might also have contributed to the aforementioned rigidities. The poor communication among the different functional units and processes clearly have inhibited the betterment of performance. Better enhancements in performance might have been possible by standardising inter-process communication as suggested in Villalba-Diez and Ordieres-Mere (2015) which is also one of the elements that lean philosophy strongly suggests.

In case B, we observed that operations performance was sustained fairly well with the integrated lean implementation. Based on the findings, the more stringent application of lean practices in both transactional as well as shop floor processes considerably contributed to such benefits. It helped to reduce waste in transactional processes, and aligning order details with what the customer asked for from the beginning. It also helped in identifying early on causes of wastes at multiple later stages of the value chain.

Therefore, a connection between the differences in lean practices implementation, with regard to locus and extensiveness, and the differences in operations performance sustenance observed in the two firms clearly emerges. This argument is in line with the findings of Fullerton *et al.* (2014) who argue that some of the gains in operations performance may be lost unless the lean implementation at shop floor is tapped and integrated with transactional processes such as accounting. Our findings further extend this argument by broadening the non-shop floor processes from just one to several transactional processes. Recent studies have also demonstrated that the transactional lean processes that connect the company with customers and suppliers are positively correlated with the lean practices within the firm (Chavez et al., 2015). Our findings confirm the importance of this phenomenon also in non-repetitive manufacturing environments.

The building of capabilities for acting flexibly is enhanced when all processes retain a larger proportion of value flow along the chain. By implementing lean in both shop floor and transactional processes simultaneously more opportunities (capabilities) for flexibly adapt to and meet customer requirements can be captured at different levels. The simultaneous implementation also seems to foster the recognition of uncertainties in the business context and accordingly enhance flexibilities within and beyond manufacturing shop floor. This means that the improvements in performance achieved through lean in shop floor processes can be ratcheted from falling back when challenged by abrupt order volume or mix changes as the ones faced by both companies A and B.

ETO orders involve considerable negotiation and information exchange before an order can be approved by a customer. Such activities often account for a large portion of the time and effort in the order fulfilment cycle. This means that to retain a significant level of performance gain in such environments, performance should be improved along the different processes which feed and support shop floor activities. This is important, because of the strong and sometime cyclical interconnectedness between the different processes in ETO organisations to effectively deliver the items ordered. Information and components need to be clearly aligned to the order from the customer as early on as possible. Even so, the unpredictability and heterogeneity inherent in ETO call for embedding and utilising flexibility.

Implementing lean across the value chain processes is also an obvious way of encouraging learning by doing. The cross-functional trainings are sources of easier reconfiguration in addition to their importance to multitasking employees for better efficiency. Together with the necessary organisational re-arrangement and recognition of employees' contribution, as evidenced by establishing frontline unit and manufacturing cells as well as incentive mechanisms of company B, helps to further sustain the achieved performance. This observation supports the findings of Bortolotti *et al.* (2015) who have discussed how the use of people-focused lean practices reshapes the organisational culture, encouraging the implementation of lean more successfully. This subsequently leads to sustaining performance from the lean implementation.

The removal of wasteful activities from multiple processes in the value chain using lean enables freeing up capacities based on changes in the prevailing context, and utilising them in a flexible manner. Lack of focus on the engineering and design perspective with lean implementation in repetitive manufacturing (Powell and Stoel, 2017) can be well addressed in this manner. Besides, the flexibilities built at multiple levels and functional areas of the organisation together with a consistent improvement commitment mean that the organisation has more possibilities to manage uncertainties effectively.

Theoretical and managerial implications

This paper provides an empirical explanation to address the lack of literature on how lean can be practically implemented and beneficial in environments that are considered not "stable". The study discusses how lean is applicable in the ETO environment using the implementation framework proposed by Bhamu and Sangwan (2014). Furthermore, the study argues that a thorough appreciation of the benefits of lean implementation in ETO requires to capture sustaining operations performance in the face of turbulent business conditions and changing order mix. The findings of this study imply that the efforts by ETO capital goods manufacturers to implement lean are well justified.

The study also shows how lean can be used to leverage flexible capabilities to be utilised in highly dynamic and uncertain context as in capital goods ETO. Lean practices in transactional processes provide capabilities for better flexibility in responding to the turbulences of the overall internal and external business environments, thus leading to more sustained and lasting performance achievements.

A managerial implication of this study is that, if the business environment entails highly complex and dynamic, as in ETO, managers could gain enhanced operations performance and succeed in sustaining it by holistically implementing lean in both transactional and shop floor processes. However, managers need to ensure that a clear lean vision is in place in order to gain implementation buy-in at both transactional and shop floor processes. Stringent work at the pre-implementation phase is necessary to avoid unnecessary setbacks later. Organisational rearrangements may be required to enable a suitable implementation. Indeed, progress in lean implementation at the shop floor may lead to performance improvements, but these will remain highly vulnerable and subject to frustrating setbacks if they are not complemented by flexible capabilities (Bortolotti et al., 2015) fostered by lean practices in transactional processes in an integrated manner.

Conclusions

This study aimed to investigate how lean implementation in capital goods ETO differ from repetitive manufacturing and the implications of this on performance gains, and performance sustenance in particular. The investigation looked at two ETO case companies for which uncertainty context factors (complexity and dynamism) as well as organisational context were fairly similar, but with significantly different operations performance gains.

The first research question sought to see if lean implementation in ETO is different from repetitive manufacturing. The findings showed that similar set of practices in the predefined bundles are observed in ETO with customisations to suit the complex and dynamic context of ETO.

The second research question focused on addressing how lean in ETO impact operations performance. In this regard, we discuss (1) the performance improvement and sustenance components of performance, and (2) how performance sustenance is fostered considering locus, extensiveness and fidelity of lean implementation. Our findings and analysis indicated that performance in ETO setting has both improvement and sustenance components, which are equally important in explaining performance implications of lean implementation. Since the former has already been largely demonstrated and discussed in literature, mainly referring to repetitive manufacturing, in the present study we focused more on the latter. We argue that sustaining achieved performance without degradation due to uncertainties, that are intrinsic to the capital goods ETO business, is vital. Through this discussion, this study extends the theoretical scope of performance measurement of implementing lean in highly uncertain context. It also implies to managers that ratcheting mechanisms to keep performance at improved levels necessary and need more attention. Such performance sustenance could be an underlying reason for the finding of Azadegan et al. (2013) on the performance enhancing impact of complexity. Lean is ultimately aimed at reducing variability and waste in the value adding processes. As such, it could be well employed by ETO firms that could utilise it to run otherwise cumbersome activities in a customised but organised manner.

We argue from our case analyses that integrative lean practices implementation both in shop floor and transactional processes tend to enable better performance sustenance. This is in agreement with the argument given by Bortolotti et al. (2015) that people-focused soft practices are necessary in addition to shop floor practices for successful lean implementation. Not surprisingly, more intensive lean practices implementation at shop floor and transactional processes seem to help performance sustenance. We did not see much observable difference in the case companies with respect to fidelity to imply such distinction in the cases. It is, however, expected that the lean practices be customised based on prevailing context, which we have observed in the case companies. The lean implementation framework of Bhamu and Sangwan, (Bhamu and Sangwan, 2014) has provided with an additional insight that a well laid out plan for lean implementation (more practices in pre-implementation) can help not only to avoid lean fatigue but also to sustain performance under uncertainties.

The study is not without limitations. As an exploratory study in a highly complex and dynamic environment, it made use of two ETO cases. However, the findings may not be directly generalisable to all ETOs as different sectors with ETO businesses may have contextual factors that require adjustments of the implementation. The study provides only a starting point in this direction. The generalisation of specific lean practices in ETO could be a challenging endeavour. Likewise, improvement benefits derived from specific practices could not be captured in this explorative study. The method adopted in this research involved the use of pre-identified practice bundles. Therefore, statements made about comparing lean practices are generalisable at relevant lean practice bundles level.

Future research may further investigate issues of differentiation and similarity of the same topic among diverse sectors of ETO business employing lean production. ETO businesses in different sectors are so different to one another that generalization is not easy. Such research may employ the lean implementation framework along with the locus, extensiveness, and fidelity dimensions for devising large scale testing and validation studies. Additional avenues for future research include integration and leveraging from improvement opportunities with other customisations related to lean practices or tools in ETO suggested in recent research. In this line, the applicability of lean in ETO manufacturing to develop capabilities for addressing uncertainties arising from unanticipated disruptions in the supply chain network can be investigated in depth.

References

Ansari, S.M., Fiss, P.C. and Zajac, Z.J. (2010), "Made to fit: How practices vary as they diffuse", *Academy of Management Review*, Vol. 35 No. 1, pp. 67–92.

Azadegan, A., Patel, P.C., Zangoueinezhad, A. and Linderman, K. (2013), "The effect of environmental complexity and environmental dynamism on lean practices", *Journal of Operations Management*, Vol. 31 No. 4, pp. 193–212.

Bhamu, J. and Sangwan, K.S. (2014), "Lean manufacturing: literature review and research issues", *International Journal of Operations & Production Management*, Vol. 34 No. 7, pp. 876–940.

Birkie, S.E. and Trucco, P. (2016), "Understanding dynamism and complexity factors in engineer-to-order, and their influence on lean implementation strategy", *Production Planning & Control*, Vol. 27 No. 5, pp. 345–359.

Bortolotti, T., Boscari, S. and Danese, P. (2015), "Successful lean implementation: Organizational culture and soft lean practices", *International Journal of Production Economics*, Vol. 160, pp. 182–201.

Browning, T.R. and Heath, R.D. (2009), "Reconceptualizing the effects of lean on production costs with evidence from the F-22 program", *Journal of Operations Management*, Vol. 27 No. 1, pp. 23–44.

Chavez, R., Yu, W., Jacobs, M., Fynes, B., Wiengarten, F. and Lecuna, A. (2015), "Internal lean practices and performance: the role of technological turbulence", *International Journal of Production Economics*, Vol. 160, pp. 157–171.

Chen, C.-S. (2006), “Concurrent engineer-to-order operation in the manufacturing engineering contracting industries”, *International Journal of Industrial and Systems Engineering*, Vol. 1 No. 1/2, pp. 37–58.

Cooney, R. (2002), “Is ‘lean’ a universal production system?: Batch production in the automotive industry”, *International Journal of Operations & Production Management*, Vol. 22 No. 10, pp. 1130–1147.

Cudney, E. and Elrod, C. (2011), “A comparative analysis of integrating lean concepts into supply chain management in manufacturing and service industries”, *International Journal of Lean Six Sigma*, Vol. 2 No. 1, pp. 5–22.

Duncan, R.B. (1972), “Characteristics of organizational environments and perceived environmental uncertainty”, *Administrative Science Quarterly*, Vol. 17 No. 3, pp. 313–327.

Eisenhardt, K.M. (1989), “Building theories from case study research”, *The Academy of Management Review*, Vol. 14 No. 4, pp. 532–550.

Fullerton, R.R., Kennedy, F.A. and Widener, S.K. (2014), “Lean manufacturing and firm performance: The incremental contribution of lean management accounting practices”, *Journal of Operations Management*, Elsevier B.V., Vol. 32 No. 7–8, pp. 414–428.

Gosling, J. and Naim, M.M. (2009), “Engineer-to-order supply chain management: A literature review and research agenda”, *International Journal of Production Economics*, Vol. 122 No. 2, pp. 741–754.

Hines, P., Holweg, M. and Rich, N. (2004), “Learning to evolve: a review of contemporary lean thinking”, *International Journal of Operations & Production Management*, Vol. 24 No. 10, pp. 994–1011.

Jadhav, J.R., Mantha, S.S. and Rane, S.B. (2014), “Exploring barriers in lean implementation”, *International Journal of Lean Six Sigma*, Vol. 5 No. 2, pp. 122–148.

Langstrand, J. and Drotz, E. (2015), “The rhetoric and reality of Lean: a multiple case study”, *Total Quality Management & Business Excellence*, pp. 1–15.

Liker, J.K. (2004), *The Toyota Way: 14 Principles from the World’s Greatest Manufacturer*, McGraw-Hill, New York.

Matt, D.T. and Rauch, E. (2014), “Implementing lean in engineer- to-order manufacturing: experiences from a ETO manufacturer”, in Modrak, V. and Semanco, P. (Eds.), *Handbook of Reasearch on Design and Management of Lean Production Systems*, IGI Global, pp. 148–172.

Naim, M.M. and Gosling, J. (2011), “On leanness, agility and leagile supply chains”, *International Journal of Production Economics*, Vol. 131 No. 1, pp. 342–354.

Nash, M. and Poling, S.R. (2008), *Mapping the Total Value Stream: A Comprehensive Guide for Production and Transactional Processes*, Productivity Press, New York.

Nightingale, D.J. and Mize, J.H. (2002), “Development of a Lean Enterprise Transformation Maturity Model”, *Information, Knowledge, Systems Management*, Vol. 3 No. 1, pp. 15–30.

Portioli Staudacher, A. and Tantardini, M. (2012), “Lean implementation in non–repetitive companies: a survey and analysis”, *International Journal of Services and Operations Management*, Vol. 11 No. 4, pp. 385–406.

Powell, D.J. and Stoel, A. van der. (2017), “Lean ETO Manufacturing”, in Netland, T.H. and Powell, D.J. (Eds.), *The Routledge Companion to Lean Management*, Routledge Taylor & Francis, New York, pp. 286–301.

Raghavan, V.A., Yoon, S. and Srihari, K. (2014), “Lean transformation in a high mix low volume electronics assembly environment”, *International Journal of Lean Six*

Sigma, Vol. 5 No. 4, pp. 342–360.

Scherrer-Rathje, M., Boyle, T.A. and Deflorin, P. (2009), "Lean, take two! Reflections from the second attempt at lean implementation", *Business Horizons*, Vol. 52 No. 1, pp. 79–88.

Shah, R. and Ward, P.T. (2003), "Lean manufacturing: context, practice bundles, and performance", *Journal of Operations Management*, Vol. 21 No. 2, pp. 129–149.

Shah, R. and Ward, P.T. (2007), "Defining and developing measures of lean production", *Journal of Operations Management*, Vol. 25 No. 4, pp. 785–805.

Sisson, J. and Elshennawy, A. (2015), "Achieving success with Lean: An analysis of key factors in Lean transformation at Toyota and beyond", *International Journal of Lean Six Sigma*, Vol. 6 No. 3, pp. 263–280.

Villalba-Diez, J. and Ordieres-Mere, J. (2015), "Improving manufacturing performance by standarization of interprocess communication", *IEEE Transactions on Engineering Management*, Vol. 62 No. 3, pp. 351–360.

Womack, J.P. and Jones, D.T. (2003), *Lean Thinking: Banish Waste and Create Wealth in Your Corporation*, Free Press, New York.

Yin, R.K. (2003), *Case Study Research: Design and Methods*, 3rd ed., Sage, Thousand Oaks.

Zorzini, M., Corti, D. and Pozzetti, A. (2008), "Due date (DD) quotation and capacity planning in make-to-order companies: results from an empirical analysis", *International Journal of Production Economics*, Vol. 112 No. 2, pp. 919–933.