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PRODUCTION MANAGEMENT

A Lean approach in the upstream phase of the product life cycle: Lean Enterprise Model practices applications and analysis from industrial use-cases

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Abstract
The Lean methodology is an interesting way to improve industrial companies' performance. To implement Lean, training appears to be an important success factor. In the early 2000s, the Lean Aerospace Initiative introduced the Lean Enterprise Model (LEM), which defines Lean practices and offers training support to companies who want to implement this method. The upstream phase of the product life cycle, from product concept to first serial deliveries, is a key period for a new product and its company. Product characteristics and internal processes defined and used during this phase directly affect companies' performances. The purpose of this study is to define LEM practices adopted by industrial companies and assess the perceived benefits and effort involved in implementing them during the upstream phase of the product life cycle. To analyse industrial practices, we conducted two surveys. A first audit concerned the adoption of LEM practices in the upstream phase of the product life cycle (203 industrial respondents). A second audit measured the perceived gain/effort rates of implementing LEM practices during this period (117 industrial respondents). This study provides a better understanding of LEM practices adoption by industrialists during the early product life and defines implementation priorities.

Keywords Product life cycle · Process improvement · Product development · Lean enterprise model

1 Introduction

Implementing Lean methodology in a company is a complex process, and its success depends on many factors. Training appears to be a fundamental basis for companies that want to implement Lean [1].

Denis-Carvalho research works, focused on Lean training, defined two different aspects of the Lean methodology: the visible one, based on clear principles and tools (just in time, …), and the invisible one, relating to philosophy (respect for workers, …). To be effective, Lean training must cover both aspects and involve all levels of the company [2].

During the 1990s and 2000s, the Lean Aerospace Initiative (LAI)—a collaboration between the United States Air Force, aerospace companies, and the Massachusetts Institute of Technology—was formed to identify and implement Lean throughout the aerospace industry. The Lean Enterprise Model (LEM) is one attractive results of the work to provide a framework model that defines Lean practices to provide training support for companies to implement Lean [3]. Twenty years later, we assume that it can be interesting to study whether the basic principles of Lean, translated into LEM practices, are adopted, and followed by industrial companies practicing Lean.

Based on a bottom-up strategy, we are interested in how industrial companies apply LEM, especially in the upstream phase of their product life cycle. This is a key period for companies because it is during this product development phase that all the characteristics of the product are defined. The analysis of the upstream phase of a company's product life cycle has shown that this period consists of several

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closely linked and interdependent processes: the product development process, the operational process, and the information system [4].

Based on this scientific context, we defined two research questions:

First, we wanted to know whether the industrialists surveyed had adopted and applied the suggested LEM practices:

Q1. Are LEM practices implemented by companies during the upstream phase of the product life cycle?

Second, we were interested on industrialist respondents' perceptions of the gain and effort of implementing LEM practices in the upstream phase of the product life cycle of their companies:

Q2. How can the gain/effort ratio be optimised to implement LEM practices in a company's upstream product life cycle?

We answered these research questions by capturing the industrial perspective. Specifically, we conducted two surveys of manufacturers to gain a better understanding of the implementation of Lean in the upstream phase of the product life cycle and the use of LEM practices.

2 2. Research context

2.1 Lean methodology

Emerging in the 1960s and 1970s, the Lean methodology is now recognised as an effective way for industrial companies to improve performance.

This methodology can be defined as a philosophy or practice targeted at achieving improvements by following the most efficient way while focusing on waste reduction. In the literature, Lean waste is defined as any activity that does not have added value for the customer [5].

Lean originated from the Japanese automotive production industry—specifically the company Toyota. The Lean methodology is largely based on its production system, the Toyota Production System (TPS). In his book *The Toyota Way*, Liker analyses how the TPS works [6]. This production system is based on the reduction/elimination of non-value-added activities such as waste (Mudas), variability (Mura), and work overload (Muri).

Womack and Jones defined in their book *Lean Thinking* [7] five principles that summarise the Lean methodology:

- Precisely identify the added value of products from the customer viewpoint.
- Determine the product value chain.
- Establish continuous value flows.
- Pull flows through the customer.
- Aim for excellence.

The Lean methodology has been adapted from manufacturing to other environments—the primary target being Lean Management. It has since been adapted to many activities such as administrative services and product development [8].

2.2 the upstream phase of the product life cycle

The upstream phase of the product life cycle corresponds to the first phase of the product life cycle.

The product life cycle concept appeared for the first time in the 1960s, following the analysis of the evolution of product markets from their appearance to their disappearance [9]. Classically, the product life cycle is represented by a "life curve" that usually shows the evolution over time of accounting units, for example, sales and turnover [10]. A bell-shaped curve represents the three phases of evolution of a product during its life. At first, an expansion phase corresponding to the marketing of the product and its possible adaptation to customers' needs. The second phase, in the form of a flat line, represents the period during the product's use by customers. The last recession phase corresponds to the obsolescence of the product because of evolutions in technology or consumption habits.

The upstream phase of the product life cycle starts with the definition of specifications, before the design of the product, through the first deliveries to the customer. These steps to achieve and obtain the final product (processes, actors, milestones, etc.) are defined and described in the innovation process of the company [11].

The first phase of the product life cycle, including the innovation process, is particularly important for companies because it condenses most of the key factors of a new product (quality/cost/delay) [12]. These characteristics and processes used by companies determine their industrial performance.

2.3 The LEM approach

To improve their industrial performance, companies may choose to implement the Lean methodology. To achieve this implementation, companies must train and coach their employees.

Between 2000 and 2012, the Lean Aerospace Initiative from MIT developed a tool triad to help companies implement the Lean methodology [13], as follows:

- The Lean Enterprise Self-Assessment Tool (LESAT): A tool to evaluate the maturity level of a company [14].
- The Enterprise Transformation Roadmap (ETR): An implementation roadmap strategy [15].
- The Lean Enterprise Model (LEM): A framework to define Lean practices [16].

The LEM tool compiles and develops 12 primary practices and 61 enabling practices based on the principles of Lean methodology (Fig. 1).

In 2020, Pontes and al. performed a study to analyse the use of practices proposed in LEM to implement Lean Office [17]. The LEM model appears to be an attractive framework for the implementation of the Lean methodology in companies.

The LEM model can be used during the upstream phase of the product life cycle of companies to improve this "key period" that defines the success of a new product and its company.

3 The research methodology

3.1 Bottom-up approach

This study is based on the case study methodology [18] and uses a bottom-up approach supported by field data. This methodology consists of collecting and analysing field data to propose a model that can be used as a reference.

Lean methodology is now well represented in the literature. In this sense, the purpose of this study is to compare this vision with the industrial reality. The aim of this study is to understand how industrial companies apply Lean methodology in the upstream phase of the product life cycle to exploit the knowledge gained and define best practices [19].

3.2 Survey methodologies

To answer our research questions, we performed two distinct surveys.

To support these surveys, we used the Microsoft Forms application. This application allowed us to ask questions in different formats, send the survey as a web link, and collect the feedback. To obtain results as close to reality as possible, we made the survey anonymous to avoid any pressure that might distort the result.

The request to participate to this study, including a link to the Microsoft Forms survey, was sent by email. The first survey took place from mid-November to mid-December 2022. We sent 923 requests and received 203 responses from industrialists. The second survey was conducted from mid-January to mid-February 2023; we sent 1,158 requests and received 117 answers from industrialists.

4 Analysis of LEM principles during the upstream phase of the product life cycle

4.1 The use of LEM principles during the upstream phase of the product life cycle

To start this study and to learn more about the use of LEM practices by companies in the upstream phase of the product life cycle, we focused on the first research question:

Q1. Are LEM practices implemented by companies during the upstream phase of the product life cycle?

To answer this question, we performed a study with a survey of industrialists.

4.1.1 Information about surveyed

To better understand the public that composed this study and to validate its representativeness, we present the information collected on the 203 respondents and their companies.

4.1.1.1 Companies activities We started the survey by asking respondents which type of economic activities their companies are involved in. The following figure (Fig. 2) shows the results. We find that 75% of respondents work in the following eight types of business sectors: metallurgy (24%), machinery and equipment/automotive (13%), electronics/electrical (13%), agri-food (7%), pharmaceutical (5%), transport/logistics (5%), study/consulting (4%), and plastics/rubber (3%). Nearly 30 other business sectors are also present (with results between 2.5% and 0.5%).

4.1.1.2 Size of companies We then asked respondents about the size of their company. This is an interesting factor because it can have an impact on organisations and decisions. The following figure (Fig. 3) shows the results for enterprise population. We can see that more than 60% of the respondents work for large structures with more than 250 employees.

4.1.1.3 Function of those surveyed The position occupied is another factor that may influence answers or the interpretation of the survey. The following figure (Fig. 4) present respondents' answers. These results show that respondents hold positions with responsibilities (hierarchical, strategic, or technical).

	Primary practices	Enabling practices
P1	Identify and optimize enterprise flow	a) Establish models and/or simulations to permit understanding and evaluation of the flow process. b) Reduce the number of flow paths. c) Minimize inventory through all tiers of the value chain. d) Reduce setup times e) Implement process owner inspection throughout the value chain. f) Strive for single piece flow g) Minimize space utilized and distance travelled by personnel and material h) Synchronize production and delivery throughout the value chain i) Maintain equipment to minimize unplanned stoppages
P2	Assure seamless information flow	a) Make processes and flows visible to all stakeholders. b) Establish open and timely communications, among all stakeholders c) Link databases for key functions throughout the value chain. d) Minimize documentation while ensuring necessary data traceability and availability
P3	Optimize capability and utilization of people	a) Establish career and skill development programs for each employee. b) Ensure maintenance, certification and upgrading of critical skills. c) Analyze workforce capabilities and needs to provide for balance of breadth and depth of skills/knowledge. d) Broaden jobs to facilitate the development of a flexible workforce.
P4	Make decisions at lowest possible level	a) Establish multidisciplinary teams organized around processes and products. b) Delegate or share responsibility for decisions throughout the value chain. c) Empower people to make decisions at the point of work d) Minimize hand-offs and approvals within and between line and support activities e) Provide environment and well-defined processes for expedited decision making
P5	Implement integrated product and process development	a) Use systems engineering approach in product design and development. b) Establish clear sets of requirements and allocate these to affected elements of the product and processes c) Definitive risk management d) Incorporate design for manufacturing, test, maintenance and disposal in all engineering phases e) Design in capability for potential growth & adaptability f) Establish effective integrated product teams g) Involve all stakeholders early in the requirements definition, design and development process h) Use the "Software Factory" Process i) Implement design to cost processes j) Maintain continuity of planning throughout the product development process
P6	Develop relationships based on mutual trust and commitment	a) Build stable and cooperative relationships internally and externally. b) Establish labor management partnerships. c) Strive for continued employment or employability of the workforce d) Provide for mutual sharing of benefits from implementation of lean practices e) Establish common objectives among all stakeholders
P7	Continuously focus on the customer	a) Provide for continuous information flow and feedback with stakeholders b) Optimize the contract process to be flexible to learning and changing requirements. c) Create and maintain relationships with customers in requirements generation, product design, development and solution-based problem solving.
P8	Promote lean leadership at all levels	a) Flow-down lean principles, practices and metrics to all organizational levels b) Instill individual ownership throughout the workforce in all products and services that are provided c) Assure consistency of enterprise strategy with lean principles and practices d) Involve union leadership in promoting and implementing lean practices
P9	Maintain challenge of existing processes	a) Establish structured processes for generating, evaluating and implementing improvements at all levels b) Fix problems systematically using data and root cause analysis c) Utilize cost accounting/ management systems to establish the discrete cost of individual parts and activities. d) Set jointly established targets for continuous improvement at all levels and in all phases of the product life cycle e) Incentivize initiatives for beneficial, innovative practices
P10	Nurture a learning environment	a) Capture, communicate and apply experience generated learning b) Perform benchmarking c) Provide for interchange of knowledge from and within the supplier network
P11	Ensure process capability and maturation	a) Define and control processes throughout the value b) Establish cost beneficial variability reduction practices in all phases of product life cycle c) Establish make/buy as a strategic decision
P12	Establish make/buy as a strategic decision	a) Level demand to enable continuous flow. b) Use multi-year contracting wherever possible. c) Minimize cycle-time to limit susceptibility to externally imposed changes d) Establish incremental product performance objectives where possible e) Program high risk developments off critical paths and/or provide alternatives

Fig. 1 LEM primary and enabling practices [16]

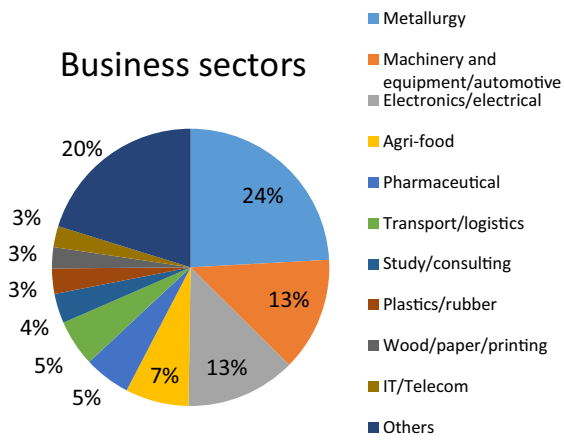

Fig. 2 Survey n°1 business sectors

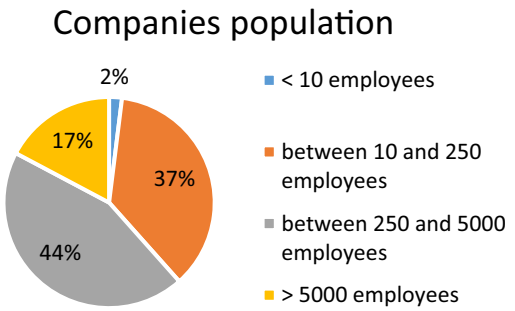

Fig. 3 Survey n°1 companies' population

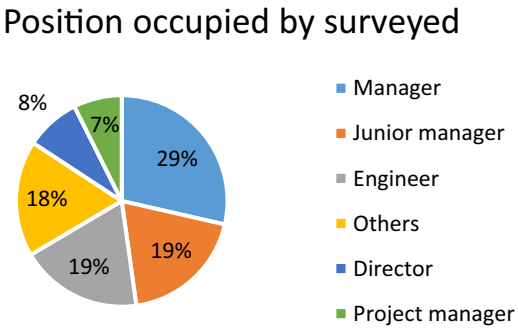

Fig. 4 Survey n°1 surveyed position

The results obtained from the respondents allow us to validate the representativeness of this study. Indeed, the results show that the main sectors of the industry are represented. There are also different company sizes, from small companies with fewer than 10 employees to large companies with more than 5,000 employees. The positions held by the respondents are also varied, with many occupying high-level positions. These elements suggest that the panel of respondents reflects a general view of the industry.

4.1.2 The use of Lean methods

Before moving on to the adherence of surveyed industrialists to LEM practices, the first question is to assess the use of Lean during the upstream phase of the product life cycle by companies.

We asked respondents whether their companies used Lean methods: 37.9% answered "no" and **62.1%** answered "**yes**." This means that just under two-thirds of the surveyed organisations use Lean methods.

To ensure the quality of the study, only results of the 126 respondents who said that their company used Lean were used for the next steps of the survey and for this study. Now that we know the proportion of companies using Lean, we can move forward in the study and ask respondents which companies use Lean in the upstream phase of the product life cycle.

To this question, 17.5% answered "no" and 82.5% answered "yes."

To summarise: **51.23%** of the respondents (104) declare that their company uses Lean in the upstream phase of the product life cycle.

4.1.3 The use of LEM practices

We now focus on the first research question, to determine whether practices of the LEM model are adopted by companies. To achieve this, we asked respondents to answer, for each of the 12 primary LEM practices, if they were applied or wished for in their companies (Fig. 5). We have also left the option of answering 'not concerned' if the practice is seen as not relevant.

Results show that six LEM primary practices are being widely applied (+55%): P7 "Continuously focus on the customer" (70.63%), P1 "Identify and optimize enterprise flow" (68.25%), P5 "Implement integrated product and process development" (64.29%), P11 "Ensure process capability and maturation" (63,49%), P9 "Maintain challenge of existing process" (59.52%), and P3 "Optimize capability and utilization of people" (55.56%). Two LEM practices stand out as widely desired (+55%): P8 "Promote Lean leadership at all levels" (59.52%) and P12 "Maximize stability in a changing environment" (55.56%). Four practices with very close results are more complex to classify: P2 "Assure seamless information flow," P4 "Make decisions at lowest possible level," P6 "Develop relationships based on mutual trust and commitment," and P10 "Nurture a Learning environment."

We also note that some practices have a significant number of "not-concerned" answers: P9 "Maintain challenge of existing process" (38.89%), P5 "Implement integrated

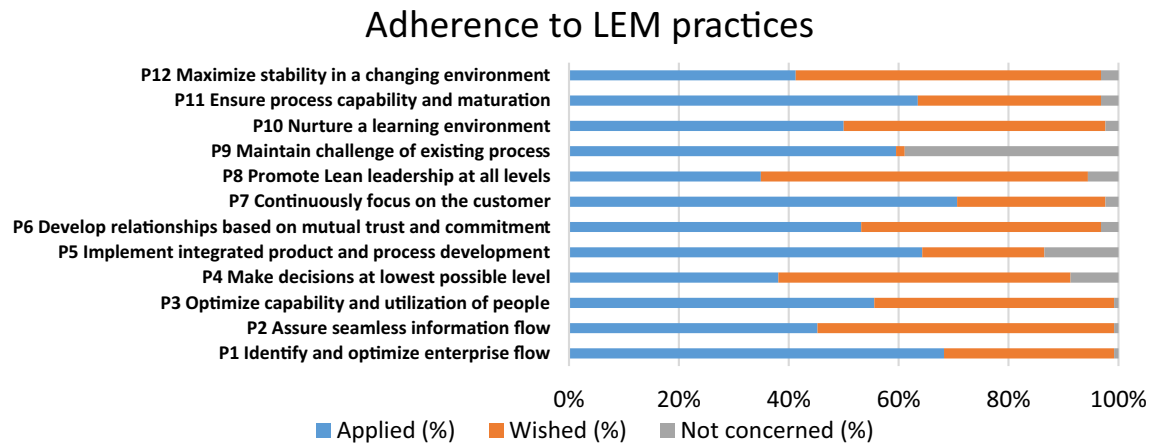

Fig. 5 Survey results about adherence to LEM primary practices by surveyed companies in the upstream phase of product life cycle

product and process development" (13.49%), and P4 "Make decisions at lowest possible level" (8.73%).

4.2 Implementation of LEM principles during the upstream phase of the product life cycle

To learn more about the implementation of LEM practices in companies during the upstream phase of the product life cycle, we now focus on our second research question:

Q2. How can the gain/effort ratio be optimised to implement LEM practices in a company's upstream product life cycle?

To move forward and answer this question, we collected direct input from industrialists who work with Lean methods by conducting a second survey.

4.2.1 Information about those surveyed

Here we used the same questions as in the first survey to establish and validate the representativeness of the public of this study. The following section presents and analyses results of the 117 respondents.

4.2.1.1 Companies' activities Of 24 sectors of activity, the largest sectors are represented in the following figure (Fig. 6). More than 75% of respondents worked in the following seven types of business sectors: metallurgy (27%), electronics/electrical (17%), machinery and equipment/automotive (9%), study/consulting (7%), transport/logistics (6%), chemistry/parachemistry (6%), and agri-food (5%). Other sectors of activity are also present with between 5% and 0.85%.

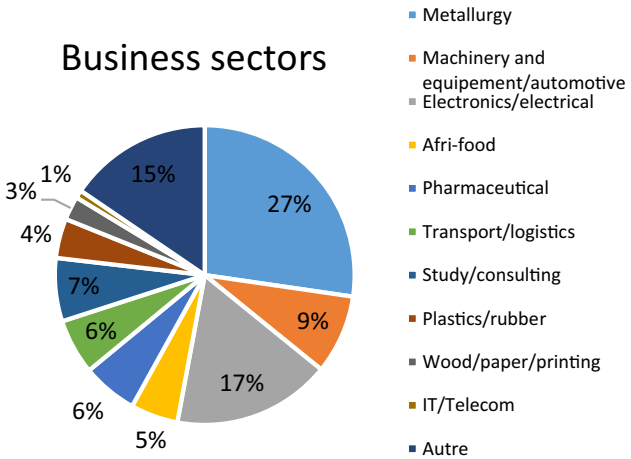

Fig. 6 Survey n°2 business sectors

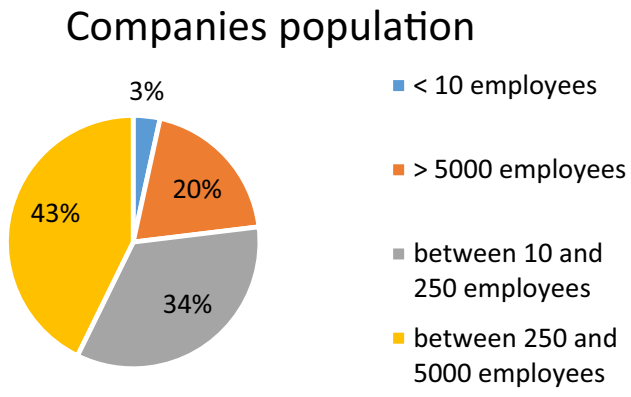

Fig. 7 Survey n°2 companies' population

4.2.1.2 Size of companies The following figure (Fig. 7) present results about the size of the companies for which

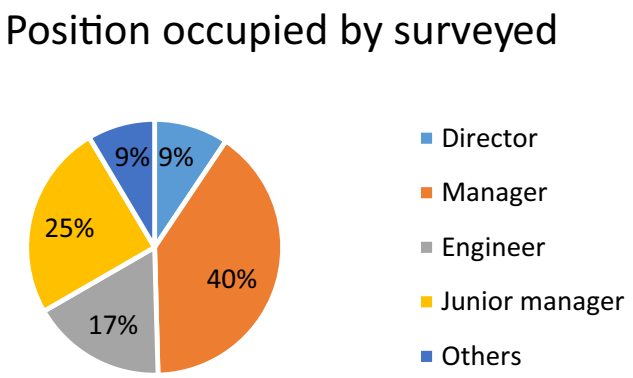

Fig. 8 Survey n°2 surveyed positions

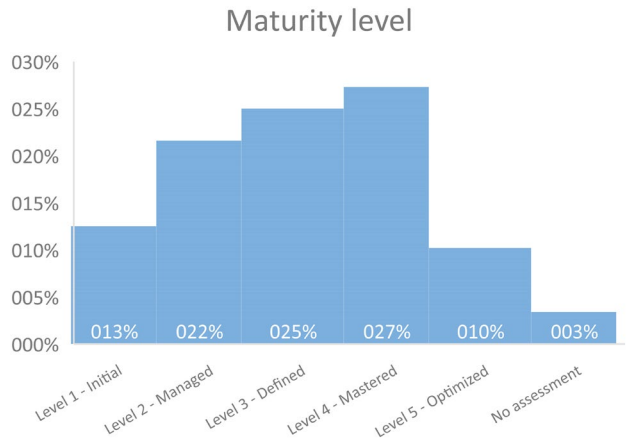

Fig. 9 Maturity level of surveyed companies

respondents are employed. These companies' population results are similar to those of the first survey.

4.2.1.3 Function of surveyed The position occupied is another factor that may influence the answers or the interpretation of the survey. The following figure (Fig. 8) represents respondents' answers. These results show that respondents hold positions with responsibility (hierarchical, strategic, or technical).

As with the first survey, in view of these results concerning respondents, we can consider that representativeness is validated.

4.2.1.4 Perceived lean maturity level To take our study further, we aimed to know more about the perceived Lean maturity level of our surveyed companies.

To achieve this assessment, we asked respondents to rate the perceived Lean maturity level of their companies using the five maturity levels defined by CMMI [20]. The first level, called "Initial," indicates that the activity is informal and unplanned. The second and third levels, "Managed" and "Defined," represent organised and controlled activities, respectively. The fourth level, "Mastered," indicates that the activity is measured and controlled. The fifth level, "Optimized," corresponds to a continuously improving activity.

We decided not to include the assessment of junior managers (29 respondents) in this part. We consider that the quotation of the Lean maturity level requires a global vision, which is difficult to comprehend for beginner staff or those with limited experience.

Results shown below (in Fig. 9) are based on 88 respondents. We can see that the perceived level of Lean maturity increases, peaking at Level 4 and decreasing at Level 5.

4.2.2 Perceived gain/effort to implement LEM practices

To answer to the second research question, the focus is on LEM practices during the upstream phase of the product life cycle perception in terms of benefit and effort by surveyed industrialists.

To measure this investment (Table 1), which is a qualitative approach, we asked respondents to rate the gain of each LEM primary practice compared to the effort required to implement it. This assessment is made for the five selected Lean tools on a scale from 1—insignificant to 5—absolutely important.

Examination of these results gives us upstanding information about how respondents understood the use of LEM primary practices. To show the results for all respondents with the perceived gain in mind, the results are in the range 3.81 for P4 "Make decisions at lowest possible level" and 4.39 for P1 "Identify and optimize enterprise flow." For the perceived effort, results were between 4.45 for P4 "Make decisions at lowest possible level" and 4.0 for P8 "Promote Lean leadership at all levels." Concerning the gain/effort ratio, results are positive for all LEM practices (ranging from 1.18 to 1.03) except P8 "Promote Lean leadership at all levels" with 0.99.

Variations were also observed between respondents who self-assessed as 1—Initial or 2—Managed and those who self-assessed as 4—Managed and 5 – Optimized.

There were differences in terms of perceived gains: 3.64 vs. 4.58 for P6 "Develop relationships based on mutual trust and commitment" and in effort: 3.97 vs. 3.61 for P11 "Ensure process capability and maturation." The following ratio was also relevant: 1.04 vs. 0.96 for P8 "Promote Lean leadership at all levels."

4.2.3 Gain/effort analysis

Based on the perceived gain and effort evaluation from respondents, to implement LEM practices in the upstream phase of the product life cycle of their companies, it was

Table 1 Survey results of the gain/effort assessment of the use of LEM practices in the upstream phase of product life cycle

		P1 Identify and optimize enterprise flow	P2 Assure seamless information flow	P3 Optimize capability and utilization of people	P4 Make decisions at lowest possible level	P5 Implement integrated product and process development	P6 Develop relationships based on mutual trust and commitment	P7 Continuously focus on the customer	P8 Promote lean leadership at all levels	P9 Maintain challenge of existing process	P10 Nurture a learning environment	P11 Ensure process capability and maturation	P12 maximize stability in a changing environment
All surveyed (117)	Gain	4,39	4,07	4,25	3,81	3,86	4,34	4,29	3,95	3,9	4,09	3,91	3,95
	Effort	3,75	3,63	3,62	3,45	3,54	3,68	3,69	4	3,57	3,52	3,75	3,85
	Ratio G/E	1,17	1,12	1,18	1,1	1,09	1,18	1,16	0,99	1,09	1,16	1,04	1,03
Surveyed level 1 and 2 (30)	Gain	4,57	4,1	4,3	3,8	4,24	3,64	4,4	4,07	3,9	4,17	4,03	3,87
	Effort	3,67	3,83	3,53	3,4	3,33	3,7	3,63	3,9	3,4	3,47	3,97	3,8
	Ratio G/E	1,25	1,07	1,22	1,08	1,19	1,15	1,21	1,04	1,15	1,2	1,02	1,02
Surveyed level 4 and 5 (33)	Gain	4,3	4,03	4,27	3,88	4,03	4,58	4,55	3,94	4,09	4,06	3,88	4,18
	Effort	3,55	3,45	3,7	3,52	3,64	3,91	3,85	4,09	3,52	3,48	3,61	3,91
	Ratio G/E	1,21	1,17	1,16	1,1	1,11	1,17	1,18	0,96	1,16	1,17	1,08	1,07

relevant for us to perform a four-diagram representation [21, 22].

By projecting the perceived effort on the x-axis and the gain on the y-axis of results obtained from the survey of the whole panel (117 respondents). Both axes placed on medians values; we obtain the following four-dials graph (Fig. 10).

The four-dials representation allows us to prioritise the 12 primary LEM practices according to their gain and effort:

- 1st dial: High-gain, low-effort practices, "First priorities for implementation": P1 "Identify and optimize enterprise flow," P3 "Optimize capability and utilization of people," P6 "Develop relationships based on mutual trust and commitment," P7 "Continuously focus on the customer."
- 2nd dial: Low gain and low effort, "Second priorities for implementation": P10 "Nurture a learning environment," P2 "Assure seamless information flow," P9 "Maintain challenge of existing process," P4 "Make decisions at lowest possible level," P11 "Ensure process capability and maturation."
- 3rd dial: High gain and high effort, "Must be implemented but requires to be scheduled and prepared": none.
- 4th dial: Low gain and high effort, "Overkill at moment; need more maturity to be implemented": P12 "Maximize stability in a changing environment," P8 "Promote Lean leadership at all levels."

4.3 Discussion about results analyses

The case study strategy used in both surveys allowed us to answer the following two research questions, defined from industrial and academic contexts:

Q1. Are LEM practices implemented by companies during the upstream phase of the product life cycle?

In our first survey, 51.23% (104 respondents) of our panel of 203 respondents stated that their companies applied Lean methodology in their upstream phase of the product life cycle. Therefore, we can state that Lean is used by companies during the product development phase.

Examining results about adherence of surveyed industrialists (126 respondents) to LEM primary practices allows us to define primary practices already adopted (+55% applied): P7 "Continuously focus on the customer" (70.63%), P1 "Identify and optimize enterprise flow" (68.25%), P5 "Implement integrated product and process development" (64.29%), P11 "Ensure process capability and maturation" (63,49%), P9 "Maintain challenge of existing process" (59.52%), and P3 "Optimize capability and utilization of people" (55.56%)—despite LEM practices not currently implemented but desired by industrial respondents (+55% wished): P8 "Promote Lean leadership at all levels" (59.52%) and P12 "Maximize stability in a

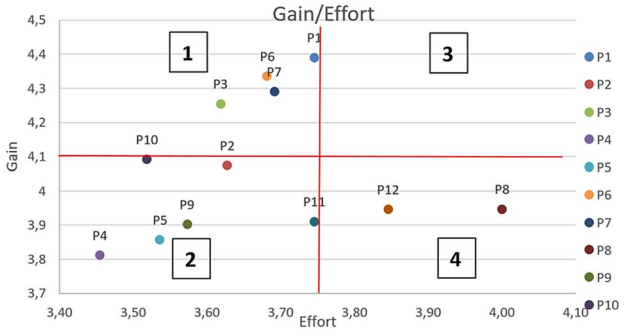

Fig. 10 Four-dials analysis of perceived gain/effort required to used LEM practices during the upstream phase of product life cycle

changing environment" (55.56%). Finally, several practices are complex to classify in the case of close results: P2 "Assure seamless information flow," P4 "Make decisions at lowest possible level," P6 "Develop relationships based on mutual trust and commitment," and P10 "Nurture a learning environment." The high rate of "not concerned" responses may be related to the nature of the organisation (no product development), the difficulty of establishing indicators, or the respondents' limited decision-making power.

Q2. How can the gain/effort ratio be optimised to implement LEM practices in a company's upstream product life cycle?

According to answers from surveyed industrialist (117 respondents) about their perceived gain/effort of implementing LEM practices during the development of a new product. Results show that for most practices (except P8 "Promote Lean leadership at all levels"), the gain/effort ratio is positive (including between the range 1.18–1.03). Survey answers also show that 1) gain/effort perception is not the same according to the level of Lean maturity of the respondents' organisation and 2) the perceived gain and effort can vary according to the Lean maturity level of the company.

Based on these results, a four-dials analysis allow us to prioritise the LEM's 12 primary practices: four practices located in the first dial, "priorities for implementation"; five in the second dial, "lowest priorities"; two in the fourth dial, "overkill"; and no practices in the third dial, "to scheduled." It is possible that principles located close to the boundary between the two dials move from one to the other depending on the level of maturity of the organisation.

The four-dials analysis prioritises the implementation of LEM practices based on an approach that has the advantage of not ranking tools one against the other, but rather classifying them according to the respondents' evaluation parameters. Based on our analysis, it seems worthwhile for those wishing to implement Lean in their organisations to follow the order of priorities presented in Sect. 4.2.3.

5 Limits and future work

The main added value of this study, supported by the bottom-up approach, is to consult industrialists about adoption and to collect feedback about LEM practices implementation during the upstream phase of the product life cycle that allow us to define implementation priority.

Nevertheless, there are some limitations to this study, e.g., the accuracy of the results is linked to the level of understanding of the respondents because this represents bottom-up work. It might also be limited by a lack of education and training. In addition, the implementation of Lean strategies and uncovered practices requires some structure and support from the company, which can make implementation more complex for smaller organisations.

The next step in a complete implementation plan of Lean for companies would be to link LEM practices and Lean waste (Muda/Muri/Mura) using links between tools and waste reduction to identify appropriate Lean tools to support corresponding LEM practices [23, 24].

Another aspect on which this study could also provide a basis would be the analysis of the impact of LEM practices on the decision-making process, as has already been described for Industry 4.0 or Lean tools [25, 26]. The integration of the LEM model in the decision-making process already described for Lean product development could add another dimension to the process [27].

Ultimately, the success of any Lean implementation depends on the adoption of the Lean methodology by employees and the way in which they live it [28]. It is therefore imperative to consider the human aspects of implementing a Lean approach—not just a technical approach based on practices or tools [29]. To successfully implement the Lean approach, it is essential to set up the right key performance indicators system (KPI's)– considering all the company's specifications—and to involve people in its construction [30].

Data availability Dataset used during this study are available from the corresponding author on request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest

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