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Lean Product Development Implementation Approach: Empirical Evidence from Indian Lean Manufacturers

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Abstract

This paper investigates the application of Lean concepts in innovation processes of a group of Indian firms which have undertaken a significant path of lean transformation both in the factory and in product development. The paper first develops an assessing framework for evaluating the Lean Product Development (LPD) transformation initiatives adopted by firms. This framework, which has been developed on the base of literature review and reviewed through a Delphy study, is subsequently used to analyse 18 Indian manufacturing companies which have embarked in LPD initiatives. The obtained empirical results contrast with the theory-based requirements of a balanced approach between process and product focus. Most of the studied companies have implemented the process-focused LPD initiatives that aim at improving the overall performance of the development process by making it more fluid and efficient through the operationalization of flow and pull principles. Lower adoption is in place for product-focused initiatives that evoke the lean principle of value and the search for effectiveness in responding to customer needs. Only a small number of firms have followed a fully integrated approach that means the adoption of a significant number of initiatives in both product and process domains. We think that the allocation of LPD transformation initiatives into proposed categories can help managers prioritize investment decisions about lean transformation in product development processes.

Key words: *Lean Product Development, Lean Manufacturing, Framework, Empirical, India*

1. INTRODUCTION

Lean manufacturing principles have been replacing conventional methods in both manufacturing and service industries for over two decades. There is substantial research that shows how lean logic and related techniques can enable radical improvements (see e. g. [83] [58] [59]).Product/service innovation is an important way for businesses to stay ahead of the competition and continue to appeal to the changing needs of existing customers [91]. Consequently, as companies are under intense pressure today to reduce product development cycle time and utilize the resources optimally, there are attempts to implement lean principles and methods in new product development processes [37].As the improvement potential of lean-inspired transformation initiatives in the context of product development (Lean Product Development - LPD) can be highly significant [39] [48], leading manufacturers from the west, faced with increased competition from emerging low-cost production countries, have been actively experimenting with LPD for a substantial period [41] [46]. Companies in developing countries, particularly Indian companies, have only recently sensed opportunities in western markets and have started pursuing the same lean techniques since they have to ensure product quality, broader range of products and higher utilization of factories [32] [33]. The major driving force is the will of these countries to move up the value chain to design and engineer next-generation, higher tech, and higher value products [42].

Obviously, difficulties abound since it is only in this decade for instance that Indian industries have realized the importance of manufacturing as a competitive weapon [85] and climbed on the bandwagon of world class manufacturing [84].Past research has been focused on the implementation of Lean principles in manufacturing processes [18] [66] [23] [89] [70]; the aim of this paper is to extend the empirical investigation of lean thinking principles to the realm of product development processes. In this perspective, we developed a framework for assessing Lean Product Development (LPD) transformation initiatives in order to explore this research question: what is the implementation approach followed by Indian companies that have undertaken a significant process of lean transformation in product development? Researchers particularly focused their inquiry on which

LPD transformation initiatives have attracted most attention; the empirical study involved 18 Indian companies.The remainder of the article is divided into the following sections. Section 2 propose a descriptive framework of LPD that defines the most internationally recognized practices of LPD in literature, while section 3 summarizes the status of LPD in India. Section 4 describes in detail the research methodology followed for conducting the study and section 5 discusses the assessment framework adopted for evaluate LPD implementation. Section 6 presents and examines the empirical evidence and, finally, section 7 contains a discussion of empirical results, implications for practice and opportunities for future research.

2. LEAN PRODUCT DEVELOPMENT: A DESCRIPTIVE FRAMEWORK

Womack *et al.* [98] dedicated one chapter to discuss lean product development (called "lean design techniques"); fifteen years later, two seminal books were published on the application of lean principles in product development: Ward and Sobek [97] proposed a visionary model of Lean Product and Process Development, and Morgan and Liker described in detail the Toyota Product Development System [56].Since then the interest of researchers and managers has grown from year to year; over time, what has clearly emerged is that the extension of Lean Thinking in managing product innovation is quite problematic: indeed, Reinertsen has clearly indicated that this difficulty is linked to the critical differences between the two fields of application - operations management and innovation management [77]. These differences include low repetitiveness of the process, level of uncertainty and risk during the development activities, presence of explorative activities that involve "trial and error", intensity of communication flows, and complexity of cross-functional integration. As such lean implementations face many hurdles [47] [6] and research shows that adaptation problems could lead to low rates of successful lean initiatives [45].In order to clearly articulate the practices that characterize the 'translation' of lean principles in the product development and innovation process, it was undertaken an exhaustive literature review; the detailed results of this analysis are reported in a study published in an international book [7]. This section of the article contains a summary of the main findings of that study - a descriptive framework that defines the most internationally recognized practices of LPD. The framework identifies a comprehensive set of 20 practices that integrates the different perspectives of LPD in the international literature; the term "practice" refers to methods or techniques used in managing and organizing specific firm activities. Table 1 shows these 20 practices and highlights for each practice the lean principle to which it refers and literature references in which the practice (albeit described using a different terminology) is presented. The definitions of LPD practices try to reflect the essence of the underlying methods and techniques, with a language that aims to resonate with the corresponding Lean Thinking principle. In section 5 the contents of each practice will be briefly described in the context of the related LPD transformation initiatives (see Table 3).

Table 1. Comprehensive set of literature-based LPD practices (source: [7]).

LPD literature-based practice	Lean Thinking Principle	Authors
1. Deep understanding of customer needs	Value	[26] [56] [81] [96]
2. Early identification of production problems	Value	[37] [56] [96] [98]
3. Integration of suppliers in the design and development process (co-design)	Value	[30] [37] [96]
4. Modular design and reduction of components	Value	[56] [77]
5. Supermarket of usable knowledge	Value	[30] [56] [80] [96]
6. Generation of alternative product concept	Value	[30] [56] [80] [96]
7. Systematic problem-solving with set-based approach	Value	[2] [26] [80]
8. Heavyweight project leader	Flow	[30] [49] [80] [98]
9. Integrated team of responsible experts	Flow	[26] [30] [80] [96] [98]
10. Obeya Room &Visual Project Board	Flow and Pull	[30] [56] [81]
11. Visual Pull Planning	Pull	[24] [80] [81]
12. Integration Events	Flow and pull	[30] [56] [77]
13. One-piece flow in the daily work in order to minimize the inefficiencies of multi-tasking	Flow	[81] [96]
14. Takt of single project (stand-up meeting)	Flow and Pull	[56] [77] [81]
15. Project portfolio Takt	Flow	[77] [81] [96]
16. One-piece flow in the project portfolio	Flow	[30] [77]
17. Integrated problem solving (concurrent engineering)	Flow	[26] [30] [37] [77] [98]
18. Anticipated & rapid prototyping	Flow	[30] [80]
19. Value Stream Mapping	Value Stream	[24] [55] [56] [80]
20. Hansei Events	Perfection	[56] [81]

3. LEAN MANAGEMENT AND PRODUCT DEVELOPMENT IN INDIA

According to the study of Womack companies in India have initiated to move from mass production model to lean production starting from the 2000's [99]. Many research reports suggest that Indian companies are right candidates for lean as waste is endemic in factories, machine idle time is high, defectives are common, supplier deliveries are often delayed, and bottlenecks choke production [69] [24] [89] [94].

Only in recent years new product development processes have picked up pace in India with increasing expectations of customers, pressure from stakeholders and intense competition in markets [32]. Also, there is a visible jump in R&D efforts that has attracted companies and made them reconsider India not only as a manufacturing hub but also as a design hub. For example, evidence suggests that new product development awareness and implementation in automotive industry surpasses other sectors in India (see e.g. [21]), probably because India is becoming a hub for global car manufacturers and these giant companies are all keen to enhance their component engineering, product design and development capabilities and augment their share in automotive knowledge-based business.

Moreover, automotive companies seem to be taking a holistic view with objectives of world class performance, world class products, rise in productivity, zero waste, and time to market compression. Indian manufacturing companies like Mahindra & Mahindra, Birla Group and Bajaj Group are collaborating as well with renowned global companies and consultancies to develop new products or infusing better product development processes.

Therefore, fortifying NPD with lean principles is an evolving phase as Indian companies seek to reduce design and cost time and attempt to make the industry competitive. Nowadays, LPD in India is well placed to enable achieve the best possible solution with less time-to-market as compared to traditional product development [32].

Although the Indian industry has taken significant strides, the academia still lags behind and is yet to explore the full depth of LPD implementation in India; while substantial improvement opportunities exist, implementation is challenging as LPD is not a simple extension of Lean Manufacturing principles in another context, as we have previously highlighted [33].

The challenges are more pronounced in developing countries like India where the access to sophisticated lean knowledge in product development is limited and employee resistance to change is substantial. Thus, it is evident that the literature lacks a consistent guiding theory on LPD and certainly the empirical data from developing countries is largely missing [40].

4. RESEARCH METHODOLOGY

Figure 1 provides a graphical representation of the research model employed to answer the research question proposed in the introduction.

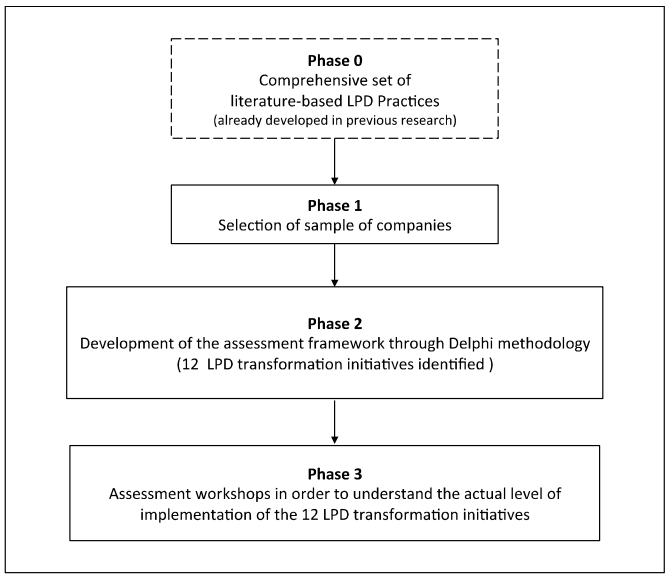

Figure 1. Graphical representation of the research model

4.1 Research method choice

We considered that a descriptive case-study approach is an appropriate method to investigate LPD implementation approach. Product development is a very complex process and implementing LPD practices is a serious managerial challenge [43]; LPD practices are not conceptually straightforward and assessing their implementation requires deep analysis and discussions. Therefore, the format of interacting with multiple informants in an interview-oriented mode is critical to understand the phenomenon. A multiple-case study approach was chosen [95] [79]; this research method allows both an in-depth examination of each case and a cross-case analysis for comparing the implementation patterns emerged in each company and enabling the elaboration of a general explanation of the phenomenon.

4.2 Phase 1: research setting

The empirical work involves 18 manufacturing companies from India that have undertaken a significant process of lean transformation both in manufacturing and product development. Usually, firms which start a lean transformation in product development processes have already implemented lean principles in the production area. In addition, in order to take part into this study companies must have started the lean path for at least five years which is traditionally considered a minimum timeframe for reaching a consistent implementation of Lean principles [68].

As illustrated in Table 2, these firms belong to different manufacturing sectors, moreover they are characterized by both discrete and process manufacturing and by different size in terms of turnover/number of employees. Case study companies have also been selected in relation to these criteria: they develop complex products or highly specialized custom build products (ETO - Engineering to Order); and/or they compete in a business where new product development performance represents a key competitive advantage.

Some of these companies are well known to the authors as they regularly collaborate with our institutions in action research projects on innovation and lean management; other companies have been identified thanks to a network of university graduate and post-graduate students.
The profile of the investigated firms is synthesized in Table 2.

Table 2. Profile of Case Companies

Company	Turnover (USD billion)	Sector	Year of initiating lean transformation
Company 1	1. 00	Automotive, Forgings	2010
Company 2	2. 50	Automobiles	2006
Company 3	0. 90	Bicycles	2011
Company 4	2. 30	Steel	2008
Company 5	2. 00	Electronics and Electrical Engineering	2007
Company 6	0. 60	Power Distribution and Protection Systems	2012
Company 7	0. 50	Automobiles	2010
Company 8	0. 10	Automotive	2011
Company 9	0. 90	Innovative Materials and Construction Products	2007
Company 10	0. 80	Automobiles	2010
Company 11	0. 50	Air conditioning	2013
Company 12	0. 25	Auto components	2012
Company 13	0. 50	Electrical Equipment	2012
Company 14	0. 10	Pumps	2009
Company 15	0. 30	Auto components	2012
Company 16	0. 10	Steam Turbines	2013
Company 17	0. 08	Compressor Motors	2013
Company 18	0. 60	Air Conditioning	2012

4.3 **Phase 2: development of the assessment framework**

In this phase, managers of the investigated firms were involved in a Delphi process in order to review our literature-based *descriptive* framework (the comprehensive set of 20 LPD practices) and collaboratively identify an *assessment* framework that could guide the evaluation of LPD implementation.
The LPD descriptive framework presented in section 2 has been drawn up through an analysis of the international literature (phase 0). Starting from that descriptive framework the aim of the phase 2 of the research model was to identify a *usable and useful assessment framework* (see [13] [57]).
Usability refers to the simplicity of frameworks to be used in a company setting and to their semantic clarity in relation to the specific organizational language and experiences of the case companies; usefulness refers to the fact that using them is perceived a value-added and feasible (in terms of time and resources needed) effort.
In this perspective, we have discussed the comprehensive set of 20 LPD practices with the managers of the companies involved in the study with a double aim: (1) to gain a shared and deep understanding of LPD practices; (2) to collaboratively identify a number of a well-defined and *self-contained LPD transformation initiatives*, that could be clearly and easily assessed. Discussions with managers have highlighted that many literature-based LPD practices are highly interdependent and underlie the same transformational objective; an exception is the practice “deep understanding of customer needs”, which has been considered too broad in scope to be correctly assessed.
The Delphi methodology was chosen for its potential to simultaneously explore similarities and differences of opinions between managers of sample companies. Delphi method is frequently employed in social science research in order to delineate and investigate current problems and critical issues [72]. Literature gives many different directions about number of Delphi group members; however here, researchers decided to align with Okoli and Pawloski [63] which state that members should be included in a number of at least 30. For this reason, an average of 2 people were selected in each company. The persons which participated in the Delphi methodology were: lean managers, lean change agents and kaizen promotion officers with a minimum of four years seniority.
The Delphi technique can be broadly group into three categories: normative Delphi, forecasting Delphi and policy Delphi [62]. The normative Delphi has been chosen for this study because the research objectives of the normative Delphi concentrates on obtaining consensus about specific topics. It is usually used to generate evaluation framework, benchmark criteria and/or indicators essentials to a particular area of concern.
We developed a Normative Delphi process following two steps. In the first step, group members were asked to discuss with the authors the comprehensive set of 20 LPD practices. This step helped generate an open, serious, and frank discussion on these practices. Participants could also reformulate the name and the description of a single practice to make it more adherent to their experience and to better explain the initiatives undertaken in their companies.
In the second step, two evaluation rounds were held with an adequate time interval between them. In the round 1, for every practice of the comprehensive set, a summary description was synthesized and the participants were asked to say if a practice stands in for a well-defined and self-contained LPD transformation initiatives. Judgments have been formulated based on a 1-5 Likert scale.
Managers’ feedback was processed using central tendency measures such as mean and median; it was considered that two rounds could be sufficient to reach adequate stability in opinions. We analyse data from both the rounds and identify patterns of agreement

through the calculation of the median as measure of central tendency (see [62]). We consider that an item achieved a stable consensus when the median gained in a new consultation differs less than 10% from the previous one, and at the same time the coefficient of variation is lower or at least equal. In the round 2, practices which had already achieved a consensus were excluded from further discussion. For the remaining items, experts were asked whether they want to reconsider previous scores and opinions. As expected, at the end of round 2, every item achieved consensus, and the process was stopped.

In the third step, practices that were not considered representative of a self-contained transformation initiative were discussed with managers. After a collaborative process of redefining and regrouping such practices (the KJ method developed by the Japanese anthropologist Jiro Kawakita [38] was employed), the final framework of the assessment framework consisting of a set of 12 transformation initiatives was developed. Value stream mapping finds a kind of exclusion since it is considered a generic lean improvement practice not to be included in the assessment tool.

This assessment framework will be discussed in section 5 (see Table 3).

4.4 **Phase 3: Assessment workshops**

In the third phase, we conducted in each company two assessment workshops with representatives from a variety of functional groups aiming to understand the actual level of implementation of the 12 LPD transformation initiatives identified. Typically, each workshop lasted about 4 hours in order to prevent the people from getting tired and was focused on a subset of transformation initiatives. On average, the working group in each company consists of 6-8 people (middle management) from different departments involved in the product development process.

Each transformation initiative was discussed in detail and scored with a 1–5 Likert-style scale (1: no implementation; 5: extensive implementation). During the workshops company documents were used to collect additional information and to better understand the current state. To assign a score to each transformation initiative we operated as follows: (1) each participant expressed his or her individual judgment; (2) individual judgments were shared in the group; (3) in the case of differing opinions we coordinated a debate in order to arrive at a consensus.

We made clear that for a LPD transformation initiative to be recorded at level 4 or 5 of the Likert scale it was necessary that two conditions were satisfied:

- the company has a formal plan for the improvement of the NPD process that includes such a transformation initiative;
- the company has made specific and documented improvement workshops aimed at implementing such a transformation initiative.

5. A FRAMEWORK FOR ASSESSING LPD IN INDIA

As discussed in section 4.3, we developed an assessment framework consisting of a set of 12 self-contained transformation initiatives; Table 3 highlights the links between literature-based LPD practices and LPD transformation initiatives.

Table 3. Literature-based practices and LPD transformation initiatives

LPD transformation initiatives	LPD literature-based practices	Focus
• Voice of Customer (VoC)	• Deep understanding of customer needs	Product
• Value Analysis and Value Engineering	• Deep understanding of customer needs	Product
• Customer-based Prioritization of Product Attributes	• Deep understanding of customer needs	Product
• Rapid Prototyping, Simulation and Testing	• Anticipated & rapid prototyping	Product
• Standardization and Product Variety Management	• Modular design and reduction of components	Product
• Set Based Concurrent Engineering (SBCE)	• Generation of alternative product concept; • Systematic problem-solving with set-based approach; • Integrated problem-solving	Product
• Supplier Integration	• Integration of suppliers in the design and development process (co-design)	Process
• Heavyweight Project Manager	• Heavyweight project leader	Process
• Visual Management	• Obeya Room; • Visual Pull Planning; Takt of single project (stand-up meeting); • Integrated team of responsible experts; • Integration events	Process
• Project Portfolio Takt & Flow	• Project Portfolio Takt; • One-piece flow in the daily work in order to minimize the inefficiencies of multi-tasking	Process
• Design for Manufacture and Assembly (DFMA)	• Early identification of production problems; • Integrated team of responsible experts	Process
• Knowledge Management	• Supermarket of usable knowledge; • Hansei events	Process

We have classified the LPD transformation initiatives into two categories: product-focused and process-focused.

A product-focused initiative is aimed at improving the overall performance of the product in terms of:

- greater harmony between the technical functionality and customer needs;
- a more robust product architecture according to the principles of standardization;
- alignment between perceived customer benefits and product costs

A process-focused initiative is aimed at improving the overall performance of the development process, searching for:

- flow in individual projects;
- cadence in project launches in order to optimize resource utilization;
- increased collaboration between internal and external actors

Product-focused initiatives evoke the lean principle of *Value* and the search for effectiveness in responding to customer needs. Process-focused initiatives evoke the lean principles of *Flow and Pull* and the search for efficiency in product development efforts.

In the remainder of this section, a brief description of the elements of the assessment framework is provided in order to make clear to the readers the content of each LPD transformation initiative and, in this way, avoiding confusion on terminology.

Voice of Customer (VoC). The value principle, in the context of innovation, is closely linked to a peculiar kind of "waste" coming from a superficial knowledge of customer needs. It is not possible to create profitable product development projects if the product does not respond to the expressed and unexpressed customer needs; the "value" is firstly defined in the customer perspective. Therefore, all those activities aiming to capture the Voice of Customer are considered central; this means going to Gemba ("the real place") by targeted interviews and product use observations through direct interaction with customers [26] [56].

Value Analysis and Value Engineering (VA/VE) is a set of techniques aimed at increasing value perceived by the customer, while implementing a systematic cost-based perspective. Typical implementations include the relation "profit to cost", the Value Index, the ratio between function and cost, and so on. Ultimately, the main goal is to express value and cost, through quantitative indicators, allowing objective comparisons between the diverse prospective solutions that could emerge for products or services. The objective to deliver optimal value at the lowest cost is pursued, by systematically evaluate the economic cost of an engineering change versus the relative change in perceived value [22] [31].

Customer-based Prioritization of Product Attributes (CPPA). Prioritization of product attributes is an important practice connected with the value principle and linked to the problem of harmonizing product concepts to customer needs. There are two well-known methodologies and tools that can be used to identify priorities in product attributes in relation to customer needs: QFD and Kano model.

QFD is a popular tool that is use by companies in order to translate customer requirements into technical features [26]. QFD implementation is a means to translate "what" into "how" i.e. it is a comprehensive practical tool to interpret colloquial and non-technical language of the customer expectations and turn them into technical terms of product specifications.

Kano's theory of product development and customer satisfaction has classified customer preferences into five dimensions namely, must-be quality, one-dimensional quality, attractive quality, indifferent quality, and reverse quality. These dimensions measure the relationship between the performance of an attribute and the level of attribute satisfaction. Thus, Kano's model contemplates on differentiating product features and offers some insights into the product attributes that are regarded important by customers [36] [50].

Rapid Prototyping, Simulation and Testing (RPST). Prototypes are used for communicating ideas to colleagues and clients, and for developing final design specifications including certain types of testing. In the recent two decades, the more popular approach tends to be that of rapid prototyping, a class of technologies that can construct physical models directly from computer-aided design files. The construction of the part or assembly is usually accomplished with 3D printing or additive layer manufacturing technology [8]. Rapid prototyping (RP) is proving significant in exploring various alternative solutions [60] [90]. Quick findings from prototypes are used to measure multiple solutions in order to show where opportunity exists for the team, to remove recurring problems in development and make fact-based decisions. According to [80] LPD embraces the idea of rapid learning cycles to optimizes product design.

Standardization and Product Variety Management (Std. and PVM). Product variety has the potential to expand the markets and profits and hence management of product variety is crucial so as to offer customers a variety of products while maintaining quality, responsiveness and on time delivery.

Moreover, the positive outcome of product variety is not to be taken for granted unless variety is managed in all stages of design, manufacturing, distribution, and even dismantling and recycling. Increased product variety can raise costs such as manufacturing costs, investments made for production systems, inventory costs, costs of transport and distribution, costs associated with product storage and display, and maintenance costs [35] [78]. Furthermore, since some research shows that increasing variety may not lead to increased demand or sales [17], defining the right range of variants with the product features combination that precisely targets the needs and resonates with customers' demands becomes a key issue in product variety management. In a LPD perspective, a company

must prevent the duplication of efforts and adopt a product platform strategy; thus, it has to engage spend energy only for those components which are really value-added for the customer.

Set Based Concurrent Engineering (SBCE). In LPD, the notion of set-based concurrent engineering considers a solution as the intersection of a number of feasible parts, rather than iterating on a bunch of individual point-based solutions. The use of set-based engineering is considered essential to find optimal solutions as cheaply and as quickly as possible [27]. In Toyota's SBCE process design participants reason about, develop, and communicate sets of solutions in parallel and relatively independently [86]. As the design progresses, they gradually narrow their respective sets of solutions based on additional information from development, testing, customer, and other participants' sets. The tenets of SBCE include mapping of design space, integrating by intersection and establishing feasibility before commitment.

Supplier Integration (SIg). The LPD perspective suggests integration with suppliers for product development activities and collaboration with only a small base of select suppliers. The caveat to close cooperation with suppliers is to not lose critical knowledge or prematurely award business to suppliers who cannot guarantee to deliver the expected quality [56]. It is noteworthy that the supplier selection and management models vary significantly across countries. According to [71] alliance and integrated relationships with suppliers should be based on trust and loyalty along with supplier speed in development, supplier's customer base, and financial stability. However, the Indian approach to supplier selection is much different than Japanese or European counterparts. In India, importance is given to top management compatibility, strategic fit, dependability, compatibility across functions, and references. LPD practice, as part of increasing collaboration between internal and external entities, should focus on interacting with suppliers for improving performance, reducing costs and solving design problems.

Heavyweight Project Manager (HPM). The concept of heavyweight project manager has been prevalent for past several decades, however, in the context of LPD firms there is greater stress since this role goes beyond operational management or integration of functions and assumes the stature of central decision-maker. LPD literature has denoted heavyweight project manager in different ways such as Project Leader, Chief Engineer, Entrepreneur System Designer, and Large-Scale Project Manager, all acknowledging the importance of this role. Apart from monitoring product development project schedule and performance targets, the heavyweight project manager also facilitates sharing of 'soft' knowledge [28], getting design teams to work well together. According to [3] and [96], the Chief Engineer is involved in analysing competitor products and translating the product definition into well-aligned goals for different functions.

Visual Management (ViM). According to [30] visual management provides opportunity to every project development project member to check performance and determine whether additional efforts are required to achieve a milestone on time. Visual boards, typically located in a dedicated place called Obeya room [56] ([81] are used for project planning and also for monitoring, reviewing, and identifying problems.

Visual management requires a rhythmic cadence in the monitoring of project activities and hence the progress meetings must be planned with high frequency in order to minimize waste of project status reporting and simultaneously improve team coordination. Visual management requires also a team of responsible experts in order to decentralize planning in the stand-up meetings – a central feature of the visual approach in project management ("visual planning").

A central element in visual planning is the notion of "integration event" or target event: a critical planned milestone for the project that pulls work through product development and helps teams to identify integration problems early. Integration events are not meetings for information "reporting" but moments of knowledge creation and integration [65] [73] [97].

Project Portfolio Takt & Flow (PPTF). Project portfolio takt means defining a standard frequency by which projects are launched (e. g. new products projects every two years; line extensions every year, etc.). This also means defining a standard duration for the different types of projects. The logic of takt aims to create "order" in the product development system and to impose a kind of "time-oriented" discipline [48] [53].

In the context of product development, the allocation of pre-defined "time windows" for projects (time-boxing), plays the same role of low inventory buffers in production: low stocks bring out the problems and require systematic problem-solving actions to ensure the system operation. Stable cycles and a cadence for project types realize predictable, similarly shaped building blocks for the overall plan. In a multiproduct development system, those rhythmic work-blocks are prerequisites to make the work flow smoothly.

The concept of flow in the project portfolio addresses the problem of resource overloading due to the implementation of many projects in parallel, often without a clear identification of priorities. Aiming at One-Piece flow in the project portfolio means to try to schedule various projects launch, so that, as much as possible, it is minimized the likelihood that people are engaged in more than one project simultaneously and, then, it is minimized the "work in progress" in the product development system.

Furthermore, it is important to create a work environment where interruptions are minimized as well as the workflow fragmentation, the so called "one-piece flow in the daily work" (e. g. allocating specific time frame of day or week to specific projects or activities).

Design for Manufacture and Assembly (DFMA). Wastes related to the missed consideration of the impact of design solutions on the efficiency and quality of manufacturing processes are widely emphasized in the Lean Development literature.

Many publications and research on simultaneous engineering have highlighted this problem since the '90s; these studies state the need to anticipate as much as possible the involvement of persons from the manufacturing area in the development process [1] [19] [88].

An integrated team of responsible experts is an effective way to anticipate the involvement of manufacturing personnel, which must guarantee that the early design drafts already meet both the needs of all internal and external stakeholders [25] [26] [86].

Knowledge Management (KM). The knowledge-creation processes are crucial in LPD from concept generation to launch. According to [45], capturing knowledge - the ability to transform data into usable knowledge - is a feature of LPD and methods range from sophisticated web-based repositories to simple checklists. Further, the explicit documentation of the best practices and lessons learned during projects needs to be accomplished systematically (e. g. through the practice of systematic reflective events - Hansei events).

Research suggests that data should be organized with absolute clarity so that the engineers can quickly review it; the accumulated knowledge base has to be regularly reviewed, updated and abridged in order to maintain its usability. Since knowledge wastes (lack of knowledge or flawed information) are known waste in LPD [3], companies have to work on "knowledge pull" and knowledge management techniques.

6. RESULTS

The main empirical evidence, that has been collected through the assessment workshops, is summarized in Table 4; each row shows which companies have assessed at level 4 or 5 of the Likert scale (as defined in section 4) the corresponding LPD transformation initiative; in this situation, the initiative can be defined as "implemented" or "adopted" by the company.

Table 4. LPD transformation initiatives implemented by sample firms

LPD transformation initiatives	Companies
• Voice of Customer (VoC)	2, 5, 6, 8, 10, 13
• Value Analysis and Value Engineering	1, 3, 5, 11, 14, 18
• Customer-based Prioritization of Product Attributes	2, 5, 17
• Rapid Prototyping, Simulation and Testing	1, 2, 6, 8
• Standardization and Product Variety Management	2, 3, 5, 6, 10, 12, 13, 15, 17, 18
• Set Based Concurrent Engineering (SBCE)	2, 11
• Supplier Integration	2, 3, 6, 7, 8, 9, 10, 14, 15, 16, 17, 18
• Heavyweight Project Manager	1, 2, 3, 4, 5, 6, 8, 10, 12, 13, 14, 15, 16, 17, 18
• Visual Management	1, 2, 5, 6, 8, 9, 10, 11, 12, 15, 16, 17
• Project Portfolio Takt & Flow	2, 4, 5, 7, 8, 10, 13, 16
• Design for Manufacture and Assembly (DFMA)	2, 10, 11, 12, 14, 15, 16, 17, 18
• Knowledge Management	1, 2, 5, 6, 13, 14, 18

Figure 2 shows the number of companies that have declared to adopt product-focused initiatives, and it is clear that standardization and product variety management is the most adopted product-focused initiative in Indian companies. Standardization has a strong connection to cost reduction, and the waste linked to a poorly managed product variety is highly visible; it is the product-focused transformation initiative whose results have a direct and objectively measurable impact on manufacturing processes. The process-centred approach of sample companies (see next paragraph) explains the diffusion of this cost-oriented product-focused initiative.

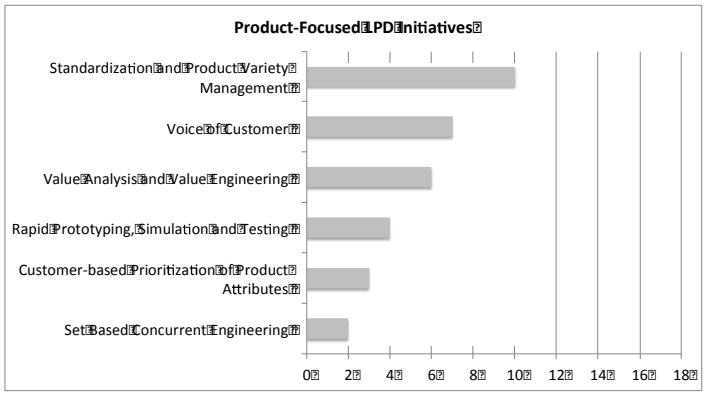

Figure 2. Adoption of Product-Focused initiatives

The voice of customer, VA/VE and Rapid Prototyping initiatives showed a limited appeal considering that less than 50% companies have implemented them. These initiatives aim at seeking greater harmony between the technical solutions and customer needs and are a vital ingredient in understanding the value proposition of novel products. The limited appeal of these initiatives can be traced back to the fact that the case companies include many automotive and auto component companies that are MNCs with a manufacturing base in India that plan for product families and entail sharing of components and platforms; the focus is on modifying products for Indian conditions rather than generating an entire innovative product design. This is a critical issue for Indian companies that aspire to be truly innovative in product design; product innovation is strongly linked to the organizational capability of discovering customer insights and consumer trends, deeply understand what customers value [14] [93], and rapidly exploring various alternative solutions.

Despite it is generally considered very important to adopt tools and methodologies to identify priorities in product attributes in relation to customer needs, the CPPA (Customer-based Prioritization of Product Attributes) transformation initiative is the least implemented along with set based concurrent engineering. The low level of implementation of CPPA confirms what we have just highlighted on the problem of the customer orientation of Indian companies.

Although Set Based Concurrent Engineering (SBCE) is an innovative and effective approach to product development, it is a very complex concept and many companies are still in the practice of point based

thinking [75]; our empirical results confirm how difficult is the implementation of this initiative**.**

Figure 3 shows the number of companies that have declared to adopt process-focused initiatives and it appears that the most adopted initiatives in the process category are focused on the organizational dimension of the development process.

Most of the sample firms operate with a team led by a Chief Engineer; over 60% of the companies follow visual management and supplier integration techniques and 50% of the companies are heavily investing in DFMA. These facts show the importance of the flow and pull principles even in the product development process.

Project Portfolio Takt/Flow and Knowledge Management are the less adopted process-focused initiatives, although they present a higher level of organizational commitment for over 40% of the companies (scoring better then all the product-focused initiatives except standardization and product variety management).

Introducing a cadence in project portfolio management is a quite sophisticated and advanced management effort [97], based on a precise standardization of project types and product development lead times; also KM techniques requires strong organizational capabilities that requires years of experimentation and learning by doing [39].

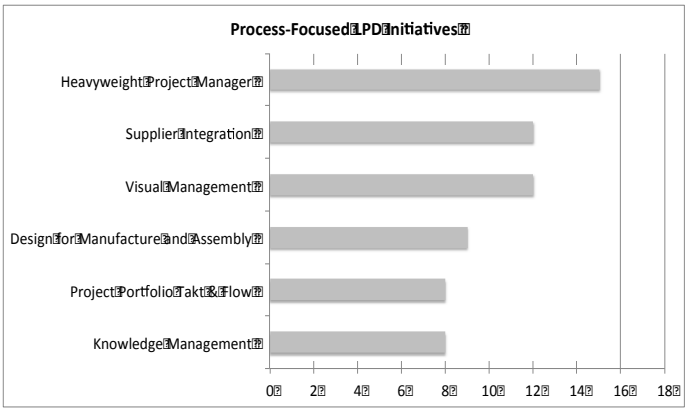

Figure 3. Adoption of Process-Focused initiatives

7. DISCUSSION AND CONCLUSION

The main objective of the paper was to explore LPD implementation approach in Indian companies. With this aim we developed an assessment tool based on the evaluation of 12 key LPD transformation initiatives, which have been organized in two separate categories: product-focused and process-focused.

Analysing the empirical results presented in Table 4, it is possible to identify different approaches in the adoption of LPD initiatives. In order to better visualize the specific approaches adopted by the sample firms, we elaborated the framework presented in Figure 4: each company is represented by a pair of values that identify the number of product-focused (horizontal axis) and process-focused (vertical axis) initiatives that have been implemented.

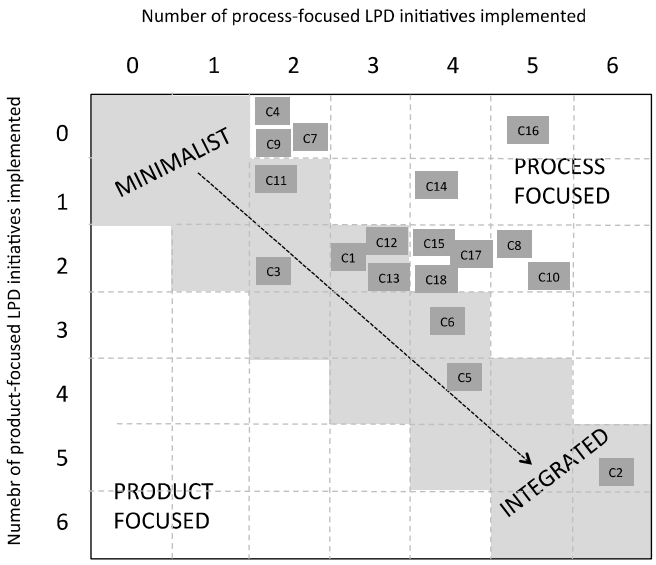

Figure 4. Patterns of Adoption of LPD initiatives

In this matrix, we have visualized a grey zone that represents a balanced approach to LPD implementation: i.e. companies falling into this zone have adopted a similar number of process-focused and product-focused initiatives (i.e. the difference that does not exceed one).

Above this diagonal are the companies that have adopted an unbalanced approach to LPD implementation as they have privileged the adoption of process-focused initiatives rather than product-focused initiatives (process-focused approach). Conversely, below the diagonal are those companies more oriented to product-focused initiatives (product-focused approach). The analyses of the distribution of firms in the matrix of Figure 4 leads to the following reflections:

- The process-focused approach is the implicit strategy pursued by most of the sample companies. These companies have therefore chosen to focus on those methodologies and tools that make product development more fluid and efficient through the operationalization of flow and pull principles.
- A fully integrated approach (which means the adoption of a significant number of initiatives in both product and process dimensions) has been followed by only one company. This company has followed a comprehensive action plan in the implementation of LPD with the aim of improving the overall performance of both the product and development process.
- Five companies (C3-4-7-9-11) have followed a path near to a minimalist approach; in these companies, the adoption of LPD initiatives is in the very early stage.
- Two firms are situated (C5-6) in the middle of the grey zone, characterized by the symmetric adoption of initiatives in both categories. This situation reflects a balanced implementation strategy.

What clearly emerges is the lower diffusion of product-focused initiatives: more than 75% of the sample of companies has implemented only 1 or 2 product-focused initiatives. Consequently, process-focused initiatives have attracted more managerial attention; only 17% of the sample adopted 1 or 2 initiatives, while 50% companies have implemented more than 50% of the process-focused initiatives.

This result emphasizes that LPD implementation is heavily influenced by the flow and pull principles, which promote the internal search for efficiency of the development process. We can infer that Indian companies have just extended the lean manufacturing arm to product development process; although lean philosophy is now resolutely rooted in organizations, experience has been built only in manufacturing to a large extent.

Our empirical results contrasts with the theory-based requirements of a balanced approach between process and product focus. Literature on LPD models [41] [56] [97] emphasizes that managerial methodologies and techniques linked to the value principle ("product-focused" LPD initiatives in our framework) should have the same focus of managerial attention as the process-oriented initiatives, aimed at flow and efficiency in the product development process. In this regard, it is interesting to highlight that the value principle is centrally positioned in the visual representation of the Allen Ward's LPD model, one of the most influential framework in the literature.

This divergence between practice and theory confirms that the application of lean concepts in product development is quite problematic, due to the critical differences between manufacturing processes and product development processes [77]. In an environment characterized by low repetitiveness and high level of uncertainty, applying the value principle is not just a matter of eliminating "waste"; it is a more complex question that relates to the problems that "product-focused" LPD initiatives try to solve: the harmony between the technical functionality and customer needs; the alignment between perceived customer benefits and product costs; and the creation of a robust product architecture.

In this perspective, the integration of the value principle with "flow and pull" principles is a not a trivial and simple endeavour; in a manufacturing environment, transforming processes in the direction of more "flow" and establishing "pull" planning systems is intrinsically and automatically connected with the elimination of waste and the pursuing of the value principle. In a product development environment, the search for value is a problem of product-market fit, which is conceptually and operationally separated from the problem of flow in the development process.

We have observed that the experience in lean manufacturing has a great influence in the conceptualization of LPD and is a powerful, albeit implicit, guide in implementation. Our empirical results show that the most adopted initiatives are those that show greater conceptual closeness to manufacturing-oriented lean thinking principles.

From a practitioner's perspective, this paper offers a framework that can be easily used to identify the LPD adoption approach of a firm. The allocation of LPD transformation initiatives in the two proposed categories (i.e. Product-Focused and Process-Focused) can enable managers to achieve greater awareness of the implementation approach adopted. In addition, it allows managers to prioritize investment decisions regarding LPD transformation and better integrate the value perspective with flow and pull principles.

Given the exploratory and descriptive nature of our research, caution is necessary regarding the potential generalization of our empirical results. The findings are based on 18 case studies of Indian companies that have undertaken a significant process of lean transformation both in the factory and in product development with a duration of at least five years.

Research developments may concern the extension of the sample in order to involve companies belonging to different industries and countries and try to generalize the empirical results. Moreover, it would be interesting to conduct a deeper analysis of the decision process followed by single companies in implementing lean thinking principles in product development; in this way it would be possible to check whether patterns of LPD adoption are correlated with, for example, the characteristics of the industrial sector to which firm belongs, the culture of the country, the competitive strategy and the competence profile of the managers involved in decision making.

Future research could also involve the development of a self-assessment tool to help companies in the diagnosis of their adoption approach of LPD initiatives; this tool could be based on a set of maturity scales, which represent a well-established methodology in the practice of organizational self-diagnosis [57] [67].

The path to LPD is still long if compared to that of Lean Production. Lean Production practices are well known and widespread as well as their deployment methods; LPD is still in its infancy. We hope that the results of this paper can stimulate the research community in empirically exploring the evolution of the Lean phenomenon beyond the factory, and help managers in implementing LPD practices in a more conscious way.

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Implementacija „Lean“ razvoja proizvoda: Empirijski rezultati „Lean“ proizvođača iz Indije

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Abstrakt

Ovaj rad istražuje primenu „Lean“ koncepta u inovacionim procesima firmi iz Indije koje su preduzele značajnu „Lean“ transformaciju kako u proizvodnom procesu tako i u razvoju proizvoda. Rad prvo razvija okvir za ocenu inicijativa za transformaciju ka „lean“ razvoju proizvoda (LRP) usvojenih od strane firme. Ovaj okvir, koji je razvijen na osnovu pregleda literature i razmotren pomoću delfi tehnike, korišćen je za analizu 18 indijskih proizvodnih kompanija koje su se uključile u LRP inicijative. Prikupljeni empirijski rezultati su u suprotnosti sa zahtevima zasnovanim na teoriji, koji podrazumevaju balansiran fokus na proizvodne procese i proizvode. Najveći broj kompanija je primenio LRP inicijative usmerene na procese, sa ciljem da se unaprede ukupne performanse razvojnog procesa tako što će ga učiniti efikasnijim kroz operacionalizaziju principa tokova i „pull“ principa. Niži je stepen usvajanja inicijativa usmerenih na proizvode, koji podrazumeva „Lean“ princip vrednosti i težnju za efektivnošću pri odgovaranju na potrebe potrošača. Veoma je mali broj firmi sa integrisanim pristupom, koji podrazumeva usvajanje značajnog broja inicijativa i u domenu proizvoda i u domenu procesa. Smatramo da podela LRP inicijativa za transformaciju u predložene kategorije može pomoći menadžerima da definišu prioritet investicionih odluka vezanih za „lean“ transformaciju u procesu razvoja proizvoda.

Ključne reči: „*Lean“ razvoj proizvoda, „Lean“ proizvodnja, okvir, empirijski, Indija*