Lean Management and Product Innovation: A Critical Review

Stefano Biazzo, Roberto Panizzolo and Alberto Maria de Crescenzo

Abstract Nowadays the management of product innovation and development processes is crucial for the survival of firms and it requires that advanced methodologies and tools should be adopted. Many companies are trying to apply the waste elimination philosophy of Lean operations into the innovation and product development processes. The application of Lean manufacturing concepts in innovation processes (Lean Innovation) is not so immediate and presents several problematic aspects. One of the greatest difficulties is not to distinguish the critical differences between the two fields of application. The aim of this work is to identify and discuss the techniques and tools which constitute Lean Innovation practices. First, the Innovation Pyramid model is proposed in order to define an integrated vision of innovation processes which is based upon three levels of activities: absorb, explore and create. Second, an extensive review of the literature has been carried out aiming to recognize the practices that characterize the "translation" of Lean principles in the innovation processes. Finally, the practices that characterize Lean Innovation are analysed throughout the proposed Innovation Pyramid model. The results of this study highlight that the Lean Innovation practices lie mainly at level 3 of the innovation pyramid (i.e. the create level). This evidence suggests that in order to enhance the firm's innovation capability it is necessary to integrate the Lean Innovation practices with other good practices coming from different research fields.

Keywords Product innovation · Lean product development · Lean practices

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1 Lean Management Outside the Factory: Lost in Translation?

John Krafcik—in a renowned article of 1988 focused on spreading the earliest results of the MIT *International Motor Vehicle Program* research—used for the first time the term "Lean" to describe the approach of production management that needs fewer resources—less space, less warehouses, fewer working hours—and simultaneously could realize products more competitive than traditional mass production in terms of time, quality and cost (Krafcik 1988).

From then, Lean manufacturing methods are replacing conventional methods in both manufacturing and service industries. Research has shown how the improvements can be radical thanks to the adoption of Lean logics and methodologies (Alsmadi et al. 2012; Shah and Ward 2003).

Excellence in production is certainly an important factor for firm's competitiveness. But product/service innovation is, in particular for western SMEs, an indispensable asset in order to avoid to succumb to price competition from companies located in emerging low cost production countries.

In this perspective, it is comforting to highlight how the potential of Lean methodologies is even higher in the context of innovation and product development. Even in the product innovation processes (or product development value streams according to the Lean jargon) significant forms of "muda" exist—that is to say waste that does not create value for the customer. The problem is that these wastes are not immediately visible and therefore they are not easily removed if appropriate methodologies to locate them are not adopted. The redesign of product innovation process can release enormous creative energy and knowledge.

Table 1 highlights the wastes that can affect the innovation activities and product development. These wastes are summarized in the classic seven types of waste identified by Taichi Ohno within production systems, with the addition of a specific important category in the context of the innovation processes: the waste of knowledge.

As highlighted by Locher (2008), this is a partial list; different organizations will produce different examples which are specific to their own development processes and corporate culture. However, there are key wastes often found in development processes regardless of organizational context. Moreover, it is important to note that the eight wastes are fundamentally interrelated and may overlap; in other words, the examples of Table 1 may fit into more than one category.

Table 1 was proposed by Locher in order to assist the Lean practitioner in developing "eyes for waste" in the product development processes. Although most people are now familiar with the waste terms proposed by Taichi Ohno, they may still have difficulty in recognizing them in the development process.

After the seminal book published in the 1990 by Womack et al. (1990), there was a progressive understanding of Lean logic implementation as resulted in the book "Lean Thinking" (1996), in which Womack and Jones developed the five

Table 1 The waste in innovation and product development

Waste category	Examples
Overproduction	Features, functionality and product performance that exceed customer requirements ("over-serve" the needs, "over-engineering", "performance over-supply") Completing design elements that are not needed for some time
Waiting	Waiting times for information, test results Waiting times for decisions Waiting times for unavailable resources (human and physical) Waiting times for system response time
Transportation	Unnecessary exchanges of information Unnecessary exchanges of responsibility
Overprocessing	"Reinventing": wasting knowledge already developed in the past Complicated and redundant documentation, not designed according to the internal customer view Unnecessary or excessive reports or paperwork Receiving and discarding useless information Ex-post projects scheduling
Inventory	Too large "information batches" which slow the learning cycles and knowledge creation Retaining documents beyond what is required
Unnecessary motion	Searching for information Meetings not properly structured and focused Work characterized by constant interruptions and changes causing high "set-up" mental time
Defects	Modifications due to design errors Modifications due to inadequate understanding of customer requirements Modifications due to service failures and missing or incomplete information
Waste of knowledge (Underutilized People)	Communication barriers (physical, social) that prevent people to interact effectively in problem analysis and troubleshooting Lack of clarity and accordance on the vision of the product to develop Archiving project information without creating re-usable knowledge Limited authority and responsibility for basic tasks Lack of knowledge sharing

Adapted from Locher (2008)

principles of Lean transformation in any kind of firm process. The five principles are a powerful and fascinating synthesis of what the future state of a "lean company" should be a lean company:

- deeply understands what is the meaning of "value" for the customer;
- knows in detail how the value is created within the company by eliminating all forms of waste;
- strives for the flow (information and materials that move quickly, without waiting) during the activities executions;

- aims to respond promptly to the market (let the customer *pull* value);
- persistently pursues continuous improvement in order to get a (not reachable) perfection.

The application of Lean concepts in innovation processes (Lean Innovation) is not so immediate and it seems problematic as there are substantial differences between manufacturing and product development contexts: during the “translation” we might lose some important issues and introduce dangerous distortions; as Donald Reinertsen has clearly shown (Reinertsen 2009), one of the greatest difficulties in implementing Lean methods in product development is *not* to distinguish the critical differences between the two fields of application. Critical differences regard basically the following aspects: the repetitiveness of the process; the level of uncertainty and risk during the development activities; the presence of explorative activities that involve "trial and error" iterations in the workflow; the intensity of communication flows and difficulty of cross-functional integration.

The objective of this work is to identify and discuss the set of techniques and tools from Lean practices that can be useful to transform innovation and product development processes of the firms.

Concerning the structure of the paper, after having described exactly the methodology employed, an integrated vision of innovation processes will be outlined by proposing the “Innovation Pyramid”model. This model states that the capability to launch new products and services in the market is based on three levels of activities: *absorb, explore and create.*

The successive section describes the main features of Lean innovation which are currently proposed in the international literature. The aim is to completely understand which are the practices that characterize the “translation” of Lean principles in the innovation processes. In the final paragraph, the set of practices that characterizes the Lean Innovation approach are analysed throughout the proposed Innovation Pyramid model. The results of this investigation highlight that the Lean Innovation practices identified lie mainly at level 3 of the innovation pyramid (i.e. the create level). This evidence suggests that in order to enhance the firm’s innovation capability it is necessary to integrate the Lean Innovation practices with other good practices coming from different research fields.

2 Methodological Considerations

The paper is based upon a literature review that was undertaken by the authors to establish a multi-perspective view on innovation activities of a firm and main features of Lean innovation principles and practices. For investigating these two phenomena, we adopted an approach that combined elements of systematic literature review (Denyer and Tranfield 2008; Rousseau et al. 2008) with the authors’ previous knowledge of the field developed over the past 20 years. Essentially, systematic reviews are formulated around research questions, and the criteria for inclusion and exclusion of papers are clearly defined at the outset.

A four-step process model proposed for content analysis in literature reviews (Mayring 2003, p. 54 cited in Seuring et al. 2005, p. 94) was adopted for this review. The four steps are: material collection, descriptive analysis, category selection and material evaluation. Material collection involves definition and delimitation of materials to be collected and search for relevant literature. At the descriptive analysis step, basic characteristics of the selected materials, such as publication distribution across journals, research methods, and number of publications per year, are examined. Decision on the choice of categories and dimensions to be used in structuring the collected materials is made at the category selection stage. Category selection is followed by material evaluation, which involved review and classification of the selected materials according to the chosen structural dimensions and categories. Only books and journal articles published were considered. The following information sources were searched: Emerald, ScienceDirect, Scopus, Springerlink, Ebscohost, Wiley, ISI, Business Source Premier, and Google Scholar. The reference lists of articles found were also examined for more relevant articles. The succeeding keywords were used for the search: “lean product development”, “lean design”, “product innovation”, “lean practices”, “innovation processes”. Each publication was analysed independently by single authors in order to extract the tools, methodologies or organizational solutions proposed in the literature for Lean transformation of innovation processes. Then, this set of tools and techniques was analysed in a crisscross pattern with the intent to integrate the different perspectives encountered and to build a framework that defines the most internationally recognized elements of Lean Innovation.

3 An Integrated Vision of Innovation Processes: The Innovation Pyramid Model

In order to completely understand the potential of Lean transformation, it is important to visualize and emphasize the complex and integrated nature of innovation activities. Figure 1 illustrates the systemic nature of innovation processes through the application of the pyramid metaphor.

The capability to launch new products and services in the market is based on a three level system of activities: *absorb, explore and create.*

- The first level concerns all activities designed to absorb knowledge from external environment through intelligence activities on markets, technology and society; intelligence activities can be both formal (e.g. purchase or internal development of a specific study on the cultural trends related to a geographical area of interest for the firm) and informal (e.g. the flow of information that derives from the existing networks of personal relationships). In Fig. 1 a data

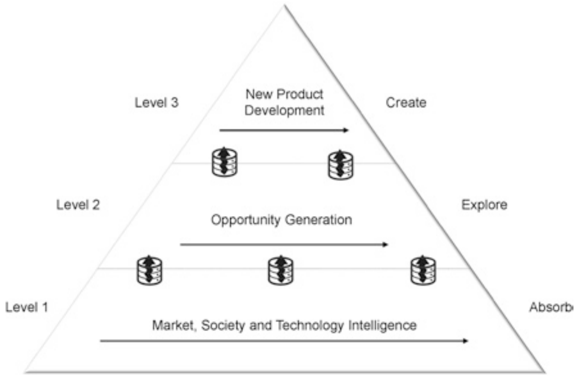

Fig. 1 The innovation pyramid: a three-level system of activities

warehouse icon represents the stock of knowledge; the arrow facing up intends to illustrate the flow of that knowledge: intelligence activities accumulate information that, at the appropriate time, may be used by exploration or creation activities.

- The second level refers to the exploration of innovation opportunities. There are different types of activities designed to generate new ideas or new technologies; they represent a "stock of opportunity" that can be the foundation of future new product development projects. Research and technological experimentation represent a classic form of exploration; but, as we will illustrate later, the firm investment in exploration activities may significantly broaden under the logic of the Open Innovation paradigm.
- The third level concerns all the activities designed to create the solutions that will be launched in the market; this is the level of product development projects, where companies try to transform knowledge concerning customer needs, technological opportunities and new product ideas into industrial technical solutions that can be produced profitably.

The pyramid metaphor represents the level of interdependence between creation, exploration and absorption activities. The capability to design new products and services that will be launched on the market is affected by the ability to generate new ideas and to explore technological opportunities; in turn this exploratory capability is influenced by the knowledge that the firm is able to absorb from the external environment and from the relational network developed over time.

It is important to note that the three levels of activities are characterized by *simultaneity*; the horizontal arrows depicted in Fig. 1 highlight this property: the systematically innovative firm is constantly and concurrently engaged in *absorption, exploration and creation* activities. Sometimes it is possible that there is a close temporal sequence between activities at different levels: for instance a "radical innovation" project could be carried out through these steps: (1) investigation on cultural trends; (2) cross-functional brainstorming in order to generate new ideas for product/service able to take advantage of specific trends; (3) selection of the most promising product idea that will be included in the portfolio of product development projects. In general, however, the activities belonging to the different levels are temporally decoupled: for instance, a deep study on the state of the art of a certain technological area of interest for the firm (level 1) is realized in order to generate a stock of knowledge that may be used in the future in various other activities (e.g. technological experimentation and product development—level 2 and 3); the "knowledge transfer" among level 1, 2, and 3 is not planned in advance.

Level 1: Absorb
This level includes all intelligence activities devised to collect and analyse actionable information about the external business environment that could affect a company's competitive position (Ashton and Klavans 1997); we can differentiate two kind of intelligence: market intelligence and technology intelligence.

Market intelligence uses multiple sources of information to create a broad picture of the company's existing market, customers, problems, competition, and social trends. These activities should aim to build an adequate stock of knowledge on three main directions:

- Customer needs: understanding needs does not mean to find out what customers desire or look for (in terms of "solutions"); understanding the needs means to reveal which are the problems that the customer is trying to solve in certain circumstances and what are the metrics that the client uses to judge the products suitability in order to "solve its problems";
- Market and social trends: knowledge of the main trends (technological, cultural, demographic, environmental, etc.) that characterize the competitive environment and more generally the society and awareness of the impact of these trends on the firm;
- Competition: analysis and comparison of competing products and competitors.

Technology Intelligence is the activity that enables companies to identify the technological opportunities and threats that could affect the future growth and survival of their business; each product is a *bundle of technologies* that has to be identified and monitored.

Level 2: Explore
Technological research has always played an important role in the exploration activity: the research and experimentation projects are, in fact, aimed at creating new technologies that could be adopted in product development projects and then incorporated into a new generation of technical solutions.

The problem that arises for small and medium enterprises is the difficulty—and in some cases the impossibility due to the insufficient firm dimension—to invest resources in activities exclusively focused on technology exploration. In these contexts, there are two alternatives:

- shifting the exploration at level 3 by incorporating massive quantity of experimentation in ordinary designing activities; as a consequence we have to accept the risks of increasing the management complexity and technical uncertainty of product development projects;

- developing collaboration and partnership with suppliers, research institutes or universities, embracing the logic of Open Innovation.

Chesbrough (2003), in his seminal book on Open Innovation, has showed that cooperation with external partners in research and technological development is a general trend absolutely independent from company dimension; in a world where knowledge is abundant and distributed, it is becoming increasingly clear that it is no longer possible—even for most relevant multinationals—to innovate relying exclusively on their own internal research strength. The innovation model based exclusively on internal research reflects the paradigm of vertical integration and control: in a hugely interconnected world, isolationism stifles innovation.

Level 3: Create
New product development is the set of activities designed to turn a product idea into a marketable product with an industrialized and profitable manufacturing process. Generally these activities can be divided in the following basic steps (Ulrich and Eppinger 2008):

- concept development, including generating alternative product concepts to satisfy a need in the market, and selecting a few concepts for further development;
- design, which involves defining the product architecture, including its major subsystems and components, and a detailed design with complete specifications of geometry and materials, and tooling design;
- testing, where the product is tested in its intended environment and refinements are made based on the results;
- production ramp-up, including manufacturing the product with the intended production system, training the workforce, and correcting any issues before full production.

There are three areas of intervention that may affect the effectiveness and efficiency of these activities:

- Design of the development process: what is the system of activities, decisions and documentation that has to be adopted as a standard for "good practices" in order to turn an idea into a feasible and marketable product?
- Project portfolio management: how are priorities set and product development projects selected and launched?
- Project management: Which organizational decisions have been adopted for managing individual projects?

4 Lean Management and Innovation: The State of the Art

In order to clearly understand which are the practices that characterize the "translation" of Lean principles in the innovation processes, we have systematically analysed the scientific and management literature by a wide selection of databases.

Each publication has been analysed independently by the single authors of this paper in order to extract the tools, methodologies or organizational solutions proposed in the literature for Lean transformation of processes innovation. Then, this set of tools and techniques has been analysed in a crisscross pattern with the intent to integrate the different perspectives encountered and to build a framework that defines the *most internationally recognized* elements of Lean Innovation. This work has identified 20 Lean Innovation practices reported in Table 2 which shows for each practice:

- the principle of lean to which it refers (in accordance with the five Lean principles proposed by Womack and Jones);
- literature references.

In this paragraph we will give a brief description of the practices.

Table 2 Lean innovation practices

Lean innovation practices	Lean thinking principle	Authors
1. Deep understanding of customer needs	Value	Haque and James-Moore (2004) Morgan and Liker (2006) Oppenheim (2004) Schipper and Swets (2009) Sehested and Sonnemberg (2010) Ward (2007)
2. Early identification of production problems	Value	Haque and James-Moore (2004) Karlsson and Åhlström (1996) Morgan and Liker (2006) Sehested and Sonnemberg (2010) Ward (2007) Womack et al. (1990)
3. Integration of suppliers in the design and development process (co-design)	Value	Hoppmann et al. (2011) Karisson and Åhlström (1996) Morgan and Liker (2006) Ward (2007)
4. Modular design and reduction of components	Value	Hoppmann et al. (2011) Morgan and Liker (2006) Reinertsen (2009)
5. Supermarket of technical knowledge	Value	Hoppmann et al. (2011) Morgan and Liker (2006) Schipper and Swets (2009) Ward (2007)
6. Generation of alternative product concept	Value	Morgan and Liker (2006) Schipper and Swets (2009) Ward (2007)

(continued)

Table 2 (continued)

Lean innovation practices	Lean thinking principle	Authors
7. Systematic problem-solving with set-based approach	Value	Baines et al. (2006) Haque and James-Moore (2004) Hoppmann et al. (2011) Morgan and Liker (2006) Schipper and Swets (2009) Ward (2007)
8. Heavyweight project leader	Flow	Baines et al. (2006) Hoppmann et al. (2011) Morgan and Liker (2006) Schipper and Swets (2009) Womack et al. (1990)
9. Integrated team of responsible experts	Flow	Haque and James-Moore (2004) Hoppmann et al. (2011) Morgan and Liker (2006) Oppenheim (2004) Schipper and Swets (2009) Ward (2007) Womack et al. (1990)
10. Obeya room and visual project board	Flow and pull	Hoppmann et al. (2011) Morgan and Liker (2006) Oppenheim (2004) Sehested and Sonnemberg (2010)
11. Visual pull planning	Pull	Haque and James-Moore (2004) Hoppmann et al. (2011) Oppenheim (2004) Schipper and Swets (2009) Sehested and Sonnemberg (2010) Ward (2007)
12. Integration events	Flow and pull	Hoppmann et al. (2011) Morgan and Liker (2006) Oppenheim (2004) Reinertsen (2009) Schipper and Swets (2009) Ward (2007)
13. One-piece flow in the daily work in order to minimize the inefficiencies of multi-tasking	Flow	Sehested and Sonnemberg (2010) Ward (2007)
14. Takt of single project (stand-up meeting)	Flow and Pull	Morgan and Liker (2006) Oppenheim (2004) Reinertsen (2009) Schipper and Swets (2009) Sehested and Sonnemberg (2010) Ward (2007)

(continued)

Table 2 (continued)

Lean innovation practices	Lean thinking principle	Authors
15. Project portfolio takt	Flow	Reinertsen (2009) Sehested and Sonnemberg (2010) Ward (2007)
16. One-piece flow in the project portfolio	Flow	Hoppmann et al. (2011) Reinertsen (2009) Sehested and Sonnemberg (2010)
17. Integrated problem solving (concurrent engineering)	Flow	Haque and James-Moore (2004) Karisson and Åhlström (1996) Reinertsen (2009) Womack et al. (1990)
18. Anticipated prototyping	Flow	Hoppmann et al. (2011) Schipper and Swets (2009)
19. Value stream mapping	Value stream	Haque and James-Moore (2004) Morgan and Liker (2006) Oppenheim (2004) Schipper and Swets (2009)
20. Hansei events	Perfection	Morgan and Liker (2006) Sehested and Sonnemberg (2010)

4.1 Deep Understanding of Customer Needs

In the literature review emerged a total convergence of recommendations that the principle of Lean Thinking "value", in the context of innovation, is closely linked to wastes coming from a non-depth knowledge of the 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 the Customer (VOC) are considered central. This means *going to gemba* ("the real place") by targeted interviews and product use observations. In order to integrate the VOC in the process development two well-known techniques are often quoted: the "house of quality" within the Quality Function Deployment (QFD) and Value Analysis.

4.2 Early Identification of Production Problems

Wastes related to the missed consideration of manufacturing implications of design solutions are widely emphasized in the Lean Development literature. Many publications and researches on simultaneous engineering have highlighted this problem since the '90 s. These studies state the need to anticipate as much as possible the involvement of persons from the manufacturing area in the development process. The early involvement is obtained by means of cross-functional teams and thanks to the anticipated scheduling of specific manufacturability "review". In this way it is possible to work on production compatibility before design completion, eliminating most of the late engineering changes. This front-loading process also isolates much of the variability that is inherent to product development allowing for speed and precision during the execution phase of product development.

4.3 Integration of Suppliers in the Design and Development Process (Co-design)

The increase in expert knowledge needed to achieve innovation, makes essential the activation of specialized knowledge sources external to the firm—in particular the suppliers. The integration with suppliers requires that the firm collaborates with a small base of suppliers, strictly selected and continuously evaluated. The Lean logics suggest that suppliers involved in co-design activities should be characterized by qualified design skills.

4.4 Modular Design and Reduction of Components

In general terms modularity is the degree to which a system's components may be separated and recombined. In manufacturing, modularity refers to the use of exchangeable parts or options in the fabrication of a product. Companies that operate with products aimed at different market segments and applications often experience a great variety in the needs of the individual customers. Modularity design is the key approach for reducing waste deriving from "useless variety". It allows to offer high customized products while maintaining efficiency and speed of delivery by standardizing those components/modules without negatively affecting the product performance.

4.5 Supermarket of Technical Knowledge

Capturing and sharing knowledge eradicate a fundamental waste: the great deal of time or effort in creating something that already exists and the repetition of errors or mistakes during the design process. The Lean approach for the development of a knowledge management system supports an approach that differs greatly from the traditional modalities focused on the creation of large database. An effective supermarket of knowledge runs as a pull system: the access and the pursuit of knowledge are simple, immediate. Moreover, it is just simple and quick to add "pieces of knowledge" to the supermarket since some template or simple guide able to capture knowledge without additional work are provided. The use of such supermarkets enhances the reusability of inter-organizational knowledge as knowledge becomes more accessible, usable, understandable and believable.

4.6 Generation of Alternative Product Concept

In general words, set-based concurrent engineering (SBCE) can be defined as engineers and product designers "reasoning, developing, and communicating about sets of solutions in parallel and relatively independently". When applying this concept to the development of product concept this means that rather than trying to identify one solution, members of the project team should instead develop a variety of design options, and then gradually eliminate alternatives, until only one option remains. An deep analysis of alternatives performed in the initial stage of the process development reduces significantly the risk that the selected solution falls short of customer needs in some respect. This "robust" product concept is a powerful method to reduce waste in downstream design activities as it reduces the uncertainties in the development process and the associated costs of reworks due to changes.

4.7 Systematic Problem-Solving with Set-Based Approach

Systematic problem-solving means facing problems with a specific discipline in the analysis and implementation process of technical solutions. Successful problem-solving approach is characterized by the following features:

- go and see: people are encouraged to see the problem with direct observations by going to the place where things happen (the Gemba);
- investigating the causes in depth: the method encourages to wonder several times the reason of the problem ("five times why"), it stimulates the mental attitude for a deep examination aimed to discover the "first cause" or the main causes;
- generating different alternatives of "resolution" (set-based approach): the technical solution is more "robust" if it is found through the exploration of many alternatives; this is especially true when the problem is complex;
- selecting the solution through the use of models, physical prototypes and computer simulations.

4.8 Heavyweight Project Leader

A Lean Innovation system is focused on the crucial importance of the project leader role regardless of the specific responsibility and authority that this role can assume (i.e. Heavyweight vs. Lightweight project leader). The project leader must mediate among trade-offs and tensions which arise from the conflicting needs generated by the functional managers. The project manager is the "father" of the project, he has the responsibility of the planning, execution and closing of the project accomplishing the stated project objectives which are cost, time, scope, and quality.

4.9 Integrated Team of Responsible Experts

The team in Lean innovation system must be integrated, that is it must be characterized by a *cross-functional* composition, so as to represent skills and expertise variety necessary for the development of the product. The use of functional groups is the solution that is most clearly associated to the achievement of significant and innovative results. *Cross-functional team*s must be made up by people who know how to apply *teamwork*. Teamwork requires the ability to listen to others' ideas, ability to display own knowledge, negotiation skills in order to identify the best solutions for the system that is being planned, strict adherence to the commitments made beside the group. Moreover, the team should consist of people who demonstrate to have two basic characteristics: *responsibility* and *competence*. Responsibility for the final result of the development, not only for the partial results of their activities. Competence that must be continually developed with purpose of becoming "experts" in their field, learning from experience and staying updated thanks to the technical and scientific literature.

4.10 Obeya Room and Visual Project Board

It is necessary to create a suitable *physical contest* for the team interactions and integration. The Obeya Room ("large room" or "war room") is the place where the team comes together and where all project information are shown permanently in an easy way visible for all (Visual Project Board). The Visual Project Board normally includes:

- a clear visualization of the project objectives ("product vision");
- the posters of project time scheduling (at various levels of detail, from major milestone to the daily plans, if it is necessary);
- a board with the display of "open issues" and "solved issues" (issue board).

Of course, other information that may be necessary to the group are included, such as the objectives details to be achieved in the various integration events (see below Visual Pull Planning), drawings, drafts, prototypes or parts of the product, etc.

4.11 Visual Pull Planning

Lean thinking recognizes the recent critical reflections on the classic project management methodologies. The central point of "project management reform" initiatives, is the rejection of the project representation as a simple network of activities in favour of a vision that the project is, first of all, a network of people. There are two fundamental consequences of this perspective, that we can define *relational*:

- planning cannot be separated from the action and therefore it is not possible (and it does not make sense) to plan the entire set of activities from the beginning. Planning is a continuous event and the details are formed gradually over time (Rolling Wave Planning).
- the project is a network of threads, commitments and actions and therefore planning must be a collaborative and social event. It is a "conversation" in which the people in charge for the activities assume mutual commitments on the tasks implementation, the temporal relationships between activities are the result of "negotiation" between the activity leaders (and not an intrinsic attribute of interdependence between activities). The duration of an activity is also the result of a "negotiation" that depends on the downstream "customer" requirements.

Pull planning is a coordination activity that must be carried out by that person who performs the operational work. The plans must be simple for upgrading and for reading and readily accessible and visible; first and foremost they must be a working tool, not a reporting tool. Waste means also to have a schedule with unnecessary details and excess information that give a false sense of control.

4.12 Integration Events

An integration event, or target event, is a critical milestone for the project that pulls work through product development and helps teams to identify integration problems early. These integration events require advance preparation, a format that allows for a lot of interaction and attention to detail, and the ability to "go and see" when the team finds problems. Integration events are not meetings of information "reporting" but moments of knowledge creation and efforts integration. Generally, it is suggested to link the integration event to the creation of an "object" (for example: the definition of "product concept", the approval of aesthetic design, the first working prototype, etc.).

4.13 One-Piece Flow in the Daily Work in Order to Minimize the Inefficiencies of Multi-tasking

In Lean Innovation system an important goal is creating a work environment where interruptions are minimized as well as the workflow fragmentation. Aiming at one-piece flow in the work has a number of advantages:

- it increases concentration and engagement in the task, with a likely increase in work quality;
- it reduces the time between the moment in which knowledge is generated and the moment in which it is utilized by others;
- it diminishes the waste due to the adaptation time required to switch from one task to another is minimized.

A simple way to achieve the one-piece flow is the concept of "time-slicing": making structured the working agenda of people by allocating specific time frame of day (or week) to specific projects or activities (e.g. in technical department it is suggested to dedicate just Fridays, or part of the day, to "requests of changing" and to prevent that such disruptions might interfere with the work of projects development, or rather to spend the morning in the high priorities projects and the afternoon in meetings, smaller projects of low priority, support activities, etc.).

4.14 Takt of Single Project (Stand-up Meeting)

Monitoring the progress of project activities must have a rhythm, a cadence (takt). These progress meetings must be planned with high frequency (Daily/Weekly Stand-up Meeting), they should be brief and have, as unique target, the project scheduling updating. These stand-up meetings aim to minimize waste of the project status reporting and simultaneously to improve the team coordination.

4.15 Project Portfolio Takt

Project portfolio takt means defining a standard frequency by which projects are launched (e.g. new products projects every two years; enlargement of the range 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 discipline regarding respect of time-frame. In the context of product development, the allocation of pre-defined "time windows" for projects, 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.

4.16 One-Piece Flow in the Project Portfolio

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 minimize the likelihood that people are engaged in more than one project simultaneously and the "work in progress" in the product development system. Obviously the ideal situation of "a team—a project" is often difficult to achieve: the search for the flow in the project portfolio simply aims to stimulate the careful management of the project portfolio and priorities. The project portfolio management is the decision-making process through which a list of product development projects is constantly reviewed and updated. Through this process the new projects are evaluated, selected and then sorted by priority. Manage in an inefficient and approximate way the projects portfolio has generally important and dangerous consequences:

- too many projects and overloaded resources: the list of active projects tends to increase too easily; the financial and personnel resources are too dispersed and the execution quality is badly affected. The lack of resources is only one side of the problem; the other side is the inability to allocate resources effectively;
- lack of distinction between the projects, which amplifies the problem of resources effective allocation;
- lack of balance between short and long term orientation. The short-term projects (cost reductions, extensions of product lines, incremental changes in performance) are certainly important; the problem is the excessive consumption of resources by these projects at the expense of riskier projects that aim to build the competitive profile in the future.

4.17 Integrated Problem Solving (Concurrent Engineering)

The integration in the problem-solving refers to the communication modalities between people working in the different phase of the development process. In concurrent engineering problem solving is integrated in the sense that:

- between the different groups there is a two-way communication flow that starts very early with an exchange of preliminary information;
- the downstream groups often start "in advance" their activities on the basis of preliminary data (or rather before that the upstream groups finished their problem-solving cycles) in order to think about the alternative solutions of upstream groups and to provide early feedback on ideas and constraints;
- communication flows are rich, intense and bilateral: they are realized mainly through face to face discussions, direct observations of issues and interactions with physical or virtual prototypes.

4.18 Anticipated Prototyping

In order to effectively explore various alternative solutions it is necessary to be very quick to comprehend the limits and the potential of what it is going to be created and designed. The speed and effectiveness in the alternatives exploration are deeply related to the ability to experiment through prototyping. A prototype can be physical or virtual, general (it represents all the product attributes) or specific (it is focused on certain attributes or subassemblies of interest). There are great differences between traditional and front-loaded prototyping which open up possibilities for more iterative development processes that fit changing environments. In traditional prototyping the number of prototypes is small, they are used late in the development process, the prototype's objective is to "verify", the cost of the prototype is high and its build time is relative high. Front-loaded prototyping means that many prototypes are build up in a quick way, their cost is low, they are used throughout the development process and the prototype's objective is to "learn". Moreover, prototype's scope is broad and vague in traditional prototyping while it is narrow and specific in front-loaded prototyping.

4.19 Value Stream Mapping (VSM)

The focus on VOC is interpretable, in the Lean logic, as the effect of a struggle against two primary kind of waste: the "defects" (products that do not grasp important customer needs) and "overproduction" (product performance that exceed customer needs). In order to set upon other types of waste in the workflow and to imagine new structuring ways of development process, it is suggested the practice of Value Stream Mapping (VSM). The specific nature of product development requires some adaptations to the traditional "manufacturing VSM", since there are not equal conditions of repetitiveness in the activities and workflows.

4.20 Hansei Events

Nowadays it is emphasized that the essential characteristic of the Lean company is to be an organization able to learn constantly and to improve systematically. A key to learning and growing in Japanese culture, is *hansei*, which roughly means "reflection." It is asserted the need to organize regularly reflective events (Hansei Events) in order to sustain continuous improvement in design and development processes. There are different types of Hansei Events, the most popular is post-mortem reflection, a program summary learning event aimed at identifying the encountered problems and to recognize improving opportunities for management methods and projects organization, capitalizing on possible negative experiences.

5 Lean Management and the Innovation Pyramid

In the following Table 3 we have linked the 20 Lean practices previously identified with the Innovation Pyramid framework. What appears clearly is that the main focus of the current Lean innovation literature lies at level 3 of the framework; however, the innovation capability of the firm is in the interplay between product development, opportunity generation, and market/technology intelligence.

Therefore, in order to soundly improve a company's innovation processes, it is necessary to integrate "lean innovation practices" with other "good practices" developed in different stream of research and managerial experimentation.

At level 1, for instance, it is particularly relevant the methodology named strategic and technology roadmapping. In recent years, roadmapping has emerged as a powerful tool to facilitate communication between technical and nontechnical communities of the firm and to capture a high level, synthesized and integrated view of the evolution of markets, products, and technology, in a graphical and visual way (Phaal and Palmer 2010; Phaal et al. 2004; Phaal and Muller 2009). Roadmapping can be thought of as a "lens" through which to visualize market, product and technology trends.

Roadmapping is, therefore, a method for highlighting opportunities for innovation and for identifying knowledge gaps (market trends not addressed by the products currently in development; technological gaps in relation the evolution of customer needs, etc.). It is worth highlighting that the result of roadmapping is not a long term plan; a roadmap is like a *radar*, a tool to capture and share knowledge and to make informed decisions. A roadmap is an evolving document, which reflects the understanding of the situation by a group; the quality of a roadmap is not measured by its forecast accuracy, but through the "movement" that it generates in terms of decisions and actions.

The benefits of roadmapping on product innovation management are twofold: on the one hand it represents the pivot around which intelligence activities revolve; on the other hand, roadmapping encourages a periodical and meaningful debate on the existing projects portfolio and it promotes consensus regarding priorities and resources allocation. The lens of roadmapping allows to "see better" the evolution of products and technologies through the definition of an *information architecture* that allows to capture and represent effectively and visually a large amount of data; the most common and flexible form is illustrated in Fig. 2, comprising a time-based, multi-layer structure addressing a series of key questions:

- The timeframes are concerned with: Where do we want to go? Where are we now? How can we get there?
- The layers address: Why do we need to act? What do we need to do? How can we do it? (Phaal and Palmer 2010)

Table 3 Lean innovation practices and the innovation pyramid

Lean innovation practices	Level 1 (Absorb)	Level 2 (Explore)	Level 3 (Create)
1. Deep understanding of customer needs	+	–	+
2 Early identification of production problems	–	–	+
3. Integration of suppliers in the design and development process (co-design)	–	–	+
4. Modular design and reduction of components	–	–	+
5. Supermarket of technical knowledge	–	+	+
6. Generation of alternative product concept	–	+	+
7. Systematic problem-solving with set-based approach	–	+	+
8. Heavyweight project leader	–	–	+
9. Integrated team of responsible experts	–	–	+
10. Obeya room and visual project board	–	–	+
11. Visual pull planning	–	–	+
12. Integration events	–	–	+
13. One-piece flow in the daily work in order to minimize the inefficiencies of multi-tasking	–	–	+
14. Takt of single project (stand-up meeting)	–	–	+
15. Project portfolio Takt	–	+	+
16. One-piece flow in the project portfolio	–	–	+
17. Problem solving integrated (concurrent engineering)	–	–	+
18. Anticipated prototyping	–	+	+
19. Value stream mapping	–	–	+
20. Hansei events	–	–	+

Layers and timeframes provide a structured framework for discussing, collecting and analysing information on the following three key issues:

- Why do I have to develop certain products?
- What to do? Which products must be planned to meet customer needs and market trends?
- How? Which technologies and resources are needed to design the planned products?

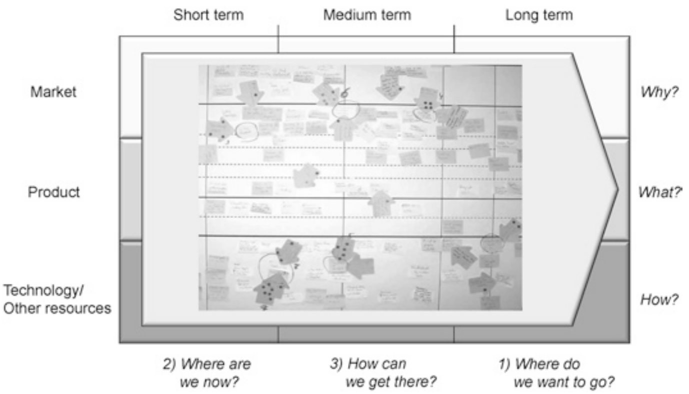

Fig. 2 The architecture of a roadmap. (Adapted from Phaal and Palmer 2010)

This format supports interaction and dialogue between different perspectives and business functions, facilitating the identification of challenges and opportunities and the alignment on action plans. Indeed one of the key benefits of roadmapping is to create a structured context of information sharing and team building in a highly interactive and engaging process.

At level 2, the recent literature on Open Innovation offers an interesting perspective for enhancing the capability of opportunity generation: the systematic management of "innovation tournaments" (Terwiesch and Ulrich 2009). An innovation tournament is a process with a fixed duration that begins with the definition of a challenge where participants must respond with a solution (it may be simply a new product idea at a conceptual level, or a prototype, a new software, etc.). There are two fundamental components of an innovation tournament: the creation of a pool of alternative ideas; and the selection of these ideas in multiple rounds of competition.

A tournament can be run on web platforms or in off-line mode through events and workshops. In off-line tournaments (Innovation Workshop) all participants work together in a creative workshop that allows participants to show their imaginative potential; in online tournaments (Innovation Contest) participants work asynchronously, interacting with a *crowdsourcing* platform—neologism coined by Jeff Howe in an article published in Wired in 2006.

The advent of social networking technologies has definitely given a dramatic boost to the development of the crowdsourcing phenomenon: crowdsourcing is the act of outsourcing a task to a "crowd" in the form of an open call; each agent from the crowd self-selects to work on its own solution to the problem, and the best solution is chosen as the winning solution (Afuah and Tucci 2012).

The real advantage of a crowd is the variety of approaches, skills and experience that individual solvers bring with them (Boudreau and Lakhani 2013). There is vast empirical evidence that the winning ideas often come from people who operate on the periphery of the field of expertise in which it is expected that the solution lies. From a conceptual point of view, a "distant" research (new ideas or opportunities are frequently *distant* from the skills and capabilities that characterize the company) is transformed into a "local" search: for the winning problem-solver the solution is "near", as it is in his own specific field of expertise (Afuah and Tucci 2012).

As Terwiesch and Ulrich (2009) emphasize, "creating innovation opportunities is sometimes compared with lightning or flying sparks—spontaneous and uncontrollable"; the deliberate management of innovation tournaments can greatly improve the sensing, screening, and evaluation of innovation opportunities that happens before development even begins.

6 Conclusions, Managerial Implications and Avenues for Further Research

Lean management can contribute greatly to the improvement of a firm's innovation capability. But it is necessary to deeply understand which innovation processes are addressed by lean-inspired practices. In this perspective we have developed a framework that offers an integrated view of innovation processes—the Innovation Pyramid. The model shows that the capability to launch new products and services in the market is based on a three level system of activities: absorb, explore and create. Therefore improving innovation processes requires a coordinated approach that encompasses the activities of the three levels.

Our extensive review of the literature has identified 20 lean innovation practices that characterize the "translation" of Lean principles in the innovation processes. These practices lie mainly at level 3 of the Innovation Pyramid, suggesting that Lean Innovation practices must be integrated with other good practices coming from different literature streams.

Companies wishing to improve their innovation processes should not merely focus their attention on the third level of the pyramid, forgetting or neglecting the other two levels. Adopting tools and practices commonly described in the lean innovation literature is not sufficient to fully develop the innovation potential of the firm.

From a managerial point of view this means that there are a number of key points that must be kept in mind when adopting Lean Innovation practices.

For example, with regard to the development of a culture for innovation and creativity, lean practices seem to be focused on incremental changes. In this way there is a risk that innovation strategy is not oriented to planning and launch (radically) new products. This is even more problematic when using methodologies such as Variety Reduction Program (which aims to support the diversification of customer needs while maintaining profitability) or Design for Manufaturing & Assembly (that is used by many company to develop product designs that use optimal manufacturing and assembly processes).

Another example is about Quality Function Deployment (which is advocate by Lean supporters as a crucial method for satisfying customers by translating their demands into design targets and quality assurance points). QFD is consistent with a continuously and incrementally approach and causes companies to stumble over disruptive innovations.

Which general lessons can be drawn from the results of this study?

First, in defining a change strategy of innovation processes it must be clear that lean principles have a limited role. Tools and methods of the first two levels of the pyramid are equally important and should be carefully evaluated.

Second, management must define and customize the "Innovation Pyramid", to clarify the scope of application of lean principles and to highlight which other frameworks of reference are important to improve the firm's innovation system.

Lastly, change programs regarding management innovation practices must be balanced along with the three levels of the pyramid. Lean thinking focus on waste, flow and pull must be matched with specific investments in the processes of absorption and exploration. The adoption of lean management in innovation requires particular caution; as claimed by Chen and Taylor (2009), "going too lean could be harmful to creativity." The elimination of waste and the pursuit of flow and pull do not represent the critical success factors in innovation processes belonging to level 1 and level 2 of the Innovation Pyramid, where instead redundancy, divergence and generation of ideas and multiple opportunities are crucial.

There are in our view two interesting research perspectives on the relationship between lean management and product innovation:

1. the identification of good practices in the non-lean-inspired literature on innovation and product development in order to define an integrated system of good practices (both "lean-inspired" and non-lean-inspired). This system could be used as a framework for the definition of a plan to strengthen the innovative capability of the company and could guide solid research studies that comprehensively analyse the impact of lean on different types of innovations.
2. the analysis of the non-lean-inspired set of good practices to identify their overarching principles and to assess their level of consistency with the five popular Lean Thinking principles proposed by Womack and Jones.

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