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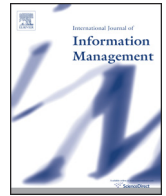


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Lean tools and methods to support efficient knowledge creation



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ABSTRACT

Continuous innovation is a key ingredient in maintaining a competitive advantage in the current dynamic and demanding marketplace. It requires an organization to regularly update and create knowledge for the current generation, and reuse it later for the next generation of a product. In this regard, an integrated dynamic knowledge model is targeted to structurally define a practical knowledge creation process in the product development domain. This model primarily consists of three distinct elements; SECI (socialization–externalization–combination–internalization) modes, 'ba', and knowledge assets. The model involves tacit knowledge and explicit knowledge interplay in 'ba' to generate new knowledge during the four SECI modes and update the knowledge assets. It is believed that lean tools and methods can also promote learning and knowledge creation. Therefore, a set of ten lean tools and methods is proposed in order to support and improve the efficiency of the knowledge creation process. The approach first establishes a framework to create knowledge in the product development environment, and then systematically demonstrates how these ten lean tools and methods conceptually fit into and play a significant role in that process. Following this, each of them is analyzed and appropriately positioned in a SECI mode depending on best fit. The merits of each tool/method are discussed from the perspective of selecting the individual mode. The managerial implication is that correct and quick knowledge creation can result in faster development and improved quality of products.

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1. Introduction

An organization must compete vigorously to thrive in the current dynamic and demanding marketplace. This requires regular enhancements in the critical attributes to develop a superior product at a cheaper cost (Cai & Tyagi, 2014). Continuous innovation and the knowledge enabling such innovation play an important role in achieving the aforesaid goals (Esterhuizen, Schutte, & Du Toit, 2012). Knowledge Bridge Consulting reported in a survey that organizations consider knowledge management as an innovation booster to adequately address market niches. A knowledge management system institutionalizes knowledge into databases or repositories. In this context, the vast knowledge management literature primarily focuses on how to capture, sort, store, locate, or retrieve knowledge to achieve internal competitive advantage (Alavi & Leidner, 2001; Ardichvili, 2008; Cortada & Woods, 1999; Date & Sinha, 2013; Davenport & Prusak, 1998; Liebowitz, 2009; Nevo & Chan, 2007). The capability to archive

lessons-learned and best practices in a knowledge management system is a pre-requisite, but does not suffice in achieving the aforesaid organizational goals. This is owing to the fact that knowledge in a computerized knowledge management system is not refreshed regularly in western companies. Typically changes are only related to adopting an advanced information technology (IT) tool. IT tools predominantly strive to manage explicit knowledge and overlooks the need for creating, updating, and utilizing new knowledge, through strong practices, tools, or methods (Morgan & Liker, 2006). This situation forces product development engineers to rely on and exploit the same old obsolete and inadequate knowledge, which results in incompetent products. Therefore, a focus on capturing knowledge that already exists through a new knowledge management scheme can be an impediment rather than advancement towards innovation (Johannessen & Olsen, 2010).

Indeed, it cannot be denied that increased internal efficiency is probably associated with the initiatives pertaining to capturing, storing, accessing, and transferring existing knowledge. But both academics and practitioners consider external growth to be the outcome of dynamic knowledge (Madhavan & Grover, 1998; Popadiuk & Choo, 2006). This has resulted in the development and adoption of various knowledge creation models in practice. These models

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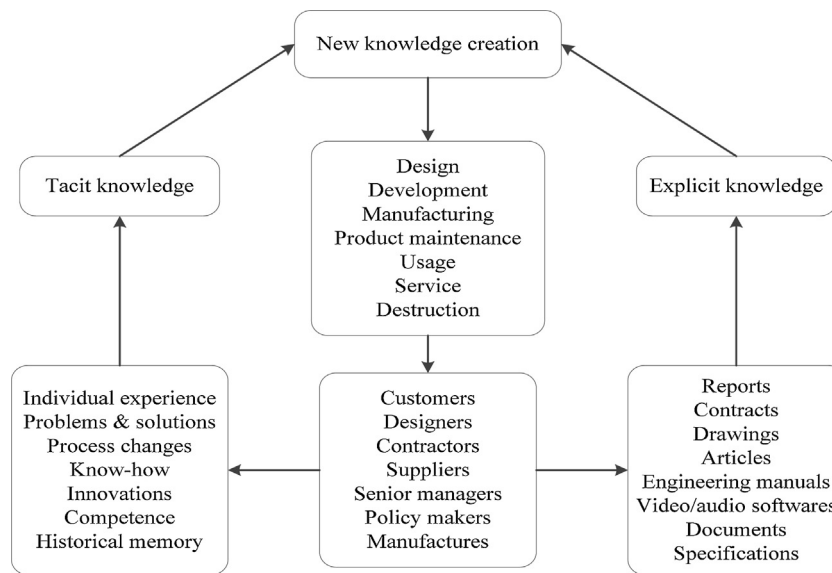


Fig. 1. Schematic representation of knowledge creation in real world.

provide details on how to create, transfer, and reuse knowledge of products, processes, and customers. This paper mainly focuses on an integrated dynamic knowledge model, which is comprised of: the SECI modes, the 'ba' (shared context), and the knowledge assets. The model predominantly illustrates how to facilitate knowledge creation and manage the way it is shared. Knowledge creation occurs continuously; for example, knowledge possessed by designers about designs in the form of explicit (reports or drawings) and tacit knowledge (experience or know-how) helps in creating knowledge when these designers come in contact with other partners such as contractors or policy makers. Their interplay results in a new knowledge, which is exploited to develop an improved design. Fig. 1 schematically represents the knowledge creation during the product development life-cycle in practical settings.

Implementation of lean tools and methods inadvertently initiates and supports knowledge creation activities. A product development team should exploit this knowledge to shorten development cycles and reduce the large costs of unplanned loop-backs. But pragmatic studies where customized lean tools and methods implemented in product development for the aforesaid purpose are lacking. This lack of studies may be due to the reasonable success of a company just by improving operational systems and understanding of lean as only a tool to eliminate waste (Tyagi, Choudhary, Cai, & Yang, 2015). Considering lean as a method only to identify and eliminate wastes creates a gap between the ways knowledge creation practices are performed in the real world. This paper is an attempt to bridge this gap. Barring the research work of Kennedy, Harmon, and Minnock (2008), Morgan and Liker (2006), and Lindlöf, Söderberg, and Persson (2012), which focused on implementing lean tools for knowledge sharing and learning in a product development environment, studies that integrate lean thinking in dynamic knowledge research are still absent in the literature. The expected contributions of this paper are two-fold. This study sheds light on how the product development domain of an organization creates, maintains, and reuses dynamic knowledge using the integrated model. From this aspect, the first contribution is to explicitly present the advanced model of knowledge creation for a product development domain and to establish its superiority. Second, the goal is to establish a relationship between the integrated model and lean thinking, and then to analyze the proposed ten tools/methods with a view to support and improve the efficiency of a knowledge creation process. Hence, this study looks beyond traditional

knowledge management by focusing specifically on knowledge creation in a product development environment.

The remainder of this paper is organized as follows: The next section reviews the relevant literature related to knowledge management and lean in the product development. Section 3 details the integrated dynamic knowledge model. A summary of lean product development is provided in Section 4. Section 5 highlights the research methodology of implementing lean tools and methods in the underlying model. Section 6 details the implementation analysis with the expected benefits from a managerial perspective, and finally, Section 7 summarizes the entire paper and provides the direction for future research.

2. Literature review

Elusiveness in specifying the definition of knowledge presents considerable challenges in conducting research (Schultze & Stabell, 2004). The work of Kane, Ragsdell, and Oppenheim (2006) emphasized this and offered a prominent but conflicting definition of knowledge. Simply put, they express that knowledge is what one already knows, and knowledge management is the practice of making that knowledge instantaneously available in a usable format to create value. After defining "knowledge," a more fundamental need is to understand how successful organizations create knowledge that makes innovations possible. Knowledge creation is defined as the process of continuously updating or increasing the knowledge base of what one knows now, rather than what one didn't know before, and keeping it accessible and usable. The basic difference between knowledge management and knowledge creation is that the former helps in filling the gaps to obtain raw data or information but the latter actually assists in problem solving. Moreover, interactions among internal and external resources can be leveraged to generate knowledge from existing knowledge unlike other inert resources (Leonard & Sensiper, 1998). Yet, research papers drawing attention to opportunities and limitations specifically related to knowledge creation are comparatively few (Yang, Fang, & Lin, 2010). Alavi and Leidner (2001) and Liu (2012) asked essential and interesting research questions related to the conditions that facilitate knowledge creation, incentives that encourage knowledge contribution, and support that triggers effective knowledge transfer among organizational units.

Towards this end, the literature describes numerous state-of-the-art dynamic knowledge models such as Nonaka (1994), Boisot (1999), Nonaka, Toyama, and Konno (2000), Nissen (2006), and Martin-de-Castro, Lopez-Saez, and Novas-Lopez (2008). The SECI model proposed by Nonaka (1994) is considered the most influential and is universally accepted. This model entails activities to create knowledge, and disseminate it within an organization. Afterwards, Boisot (1999) exploited the “Theory-of-Information” to develop the ‘I-Space’ conceptual framework, which consists of three phases: codification, abstraction, and diffusion. This model is not comprehensively applicable in practical settings, and remains an abstract and complementary tool suitable for understanding knowledge dynamics. Further, the concept of knowledge flows in the dimensions of time and space inspired Nissen’s model of knowledge dynamics (Nissen, 2006). The difference between knowing and understanding is the main driving force for knowledge flow and corresponds to the emitter and receiver in physics. However, Nissen (2006) failed to discuss core constituents like the knowledge gradient and the process of knowledge flow. Martin-de-Castro et al. (2008) proposed an Epistemological–Ontological (EO)-SECI knowledge creation model, which is an extended version of the SECI model of Nonaka (1994). This model is most useful when it is used to demonstrate knowledge dynamics in a knowledge intensive environment. Drawing on prior work, Nonaka et al. (2000) further extended the basic SECI model by unifying two more elements: ‘ba’ and knowledge assets, with SECI, where ‘ba’ is a physical, virtual, or mental space of shared aspects where knowledge is generated. Among all, the integrated dynamic knowledge model proposed by Nonaka et al. (2000) is the most advanced and hence has been targeted in this research. Details of this model are provided in Section 3.

Next, the applicability of lean tools and methods that can improve the efficiency of a knowledge creation process in the integrated dynamic knowledge model proposed by Nonaka et al. (2000) is investigated in this research. Authors such as Oppenheim (2004) and Locher (2008) offered lean product development (LPD) as a method to identify and eliminate wastes similar to lean manufacturing. On the contrary, LPD has also been explained as a method of capturing, transferring, and using/reusing knowledge (Kennedy et al., 2008; Ward, 2007). Hines, Francis, and Found (2006) provided a framework to understand the evolution of lean from conceptual and implementation aspects of organizational learning. Kennedy et al. (2008) concentrated on the importance of knowledge by separating product flow and knowledge flow. The former derives short term benefits by delivering products ready to be produced and sold, whereas the later aims to build knowledge about technology, customers, and processes for long term gains. A few works encountered in the literature have also analyzed the basic SECI model in a product development environment. Hoegl and Schulze (2005) presented a set of non-lean practices to support knowledge creation without particularly considering the SECI model. Madhavan and Grover (1998) and Schulze and Hoegl (2006) compared the SECI modes with product development phases to advocate its importance in the performance improvement analysis. Bratianu and Orzea (2010) and Bratianu (2012) critically analyzed the SECI model by applying entropy laws to understand the conversion process and then presented characteristics of other models to compare with it. Andreeva and Ikhilchik (2011) presented a theoretical model to analyze the applicability of the SECI model in a Russian culture context. They basically discussed the model and challenged the mainstream assumptions of universal applicability. Easa (2012) discussed the methodological aspects to examine the applicability of the SECI model in knowledge creation and its effects on innovation in Egyptian banks. Frank and Echeveste (2012) proposed knowledge transfer

among development teams as a method to identify improvement opportunities without considering SECI model. Lindlöf et al. (2012) studied LPD from SECI relevance within a product development environment. Further, Murphy and Salomone (2013) used social media to facilitate knowledge transfer in complex engineering processes. Despite all aforesaid focuses, the literature review did not reveal any particular study that put lean thinking in the context of knowledge creation research. The past literature primarily targeted a knowledge transfer process as a part of a knowledge creation process.

The authors were motivated predominately by the research work of Hoegl and Schulze (2005) and Lindlöf et al. (2012). Hoegl and Schulze (2005) proposed a set of non-lean tools to support knowledge creation without focusing on how knowledge creation happens in the SECI model. Further, Lindlöf et al. (2012) primarily focused on knowledge transfer only and analyzed limited LPD tools in the context of the basic SECI model. Frank and Echeveste (2012) and Murphy and Salomone (2013) also discussed knowledge transfer within the product development domain for different objectives without considering any particular process.

This research attempts to address the aforesaid gaps that are encountered in the literature. This article extends the research work of Lindlöf et al. (2012) and discusses an advanced form of the SECI model from knowledge creation perspectives and analyzes a number of lean tools/methods to improve the efficiency of a knowledge creation process. No study in the literature, to the best of our knowledge, targeted the application of various lean tools and methods to improve the efficiency of an integrated dynamic knowledge model. The underlying proposition behind this is: *the quality of products delivered by a firm is directly proportional to the efficiency of knowledge creation*. Consequently, this article goes beyond a large and growing literature on knowledge management to address the challenges of knowledge creation in supporting product development. This study proposes a comprehensive list of lean and non-lean tools and methods in an implementation framework. This research focuses on the processes that employees perform during their daily activities, and considers them from a knowledge creation perspective. The present model offers a general implementation approach, which can be extended to other sectors such as services and marketing. An integrated dynamic knowledge model to illustrate practical knowledge creation is detailed in the next section.

3. Integrated dynamic knowledge model

Existing knowledge within an organization may be exploited in dealing with problems by exploring, defining, and developing their solutions. During this problem solving exercise, teams not only take actions to solve them, but they also gain dynamic knowledge (Fig. 2). Both environment and organization interacts with each other and absorbs the required changes through knowledge creation. Here knowledge is being created (instead of just processing the information) through a nexus of interaction between team members, problem solving actions, and tasks performed. Therefore, knowledge creation follows a spiral shaped path by oscillating between sharply contrasted concepts such as order and chaos, micro and macro, part and whole, mind and body, tacit and explicit, self and other, and internal and external. Nonaka et al. (2000) presented an argument that such dialectical thinking plays an important role in transcending and synthesizing contradictions, which ultimately leads towards dynamic knowledge. An organization can possess a stock of knowledge, such as technology, which may become irrelevant in the future. Gained new knowledge and its application is the major resource for an organization’s survival. Therefore, the dynamic nature of knowledge is the prominent force for realizing the strength of an organization.

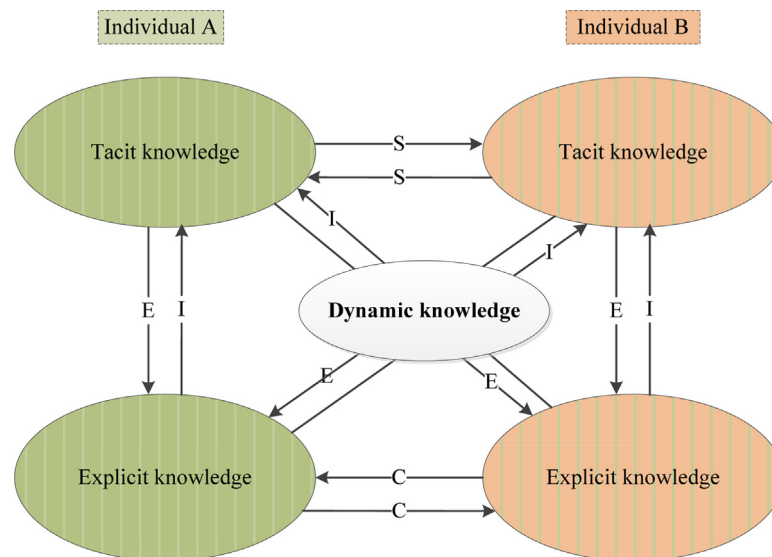


Fig. 2. Linear representation of knowledge creation between two individuals A and B. S, E, C, and I are socialization, externalization, combination, and internalization modes, respectively.

3.1. SECI modes

According to [Nonaka et al. \(2000\)](#), knowledge is divided into two types: explicit knowledge and tacit knowledge. Explicit knowledge can be presented in the form of a code, in language, and in written reports using data, scientific formulas, and manuals. Therefore, it can be communicated, processed, transmitted, and stored relatively easily. On the other hand, tacit knowledge refers to knowledge, which is only known by an individual and is difficult to communicate to the rest of the organization. It is personal knowledge embodied in actions, attitudes, commitments, emotions, and behaviour, and is difficult to codify sufficiently to communicate in a 'language.' It can only be learned by sharing experiences, and by observation and imitation ([Hall & Andriani, 2002](#)). Facts and theories—i.e. 'knowing-about,'—fall under the category of explicit knowledge, whereas skills to perform any task or job, 'knowing-how,' are in the realm of tacit knowledge. It is very difficult or nearly impossible for anyone to learn and develop 'know-how' skills just by reading or by watching audio/video media. The individual has to indulge in a hands-on experience in order to gain tacit knowledge. Among the two, tacit knowledge is more important owing to its "know-how" contribution towards continuous innovation.

Although tacit knowledge is a source of competitive advantage, it quickly loses its meaning without explicit knowledge. They complement each other and the absence of one undermines the power of the other. [Nonaka et al. \(2000\)](#) stated that their (tacit and explicit) interplay is required for dynamic knowledge. The four-stage spiral model abbreviated as SECI modes is used to depict four separate modes: socialization, externalization, combination, and internalization. The beginning point of this spiral is socialization, where the exchange of tacit knowledge at the individual level is used, without specifying any particular language, to create knowledge. For example, children imitate the behaviour of their parents and learn from it. This is followed by an externalization mode where tacit knowledge is transformed into explicit knowledge to create knowledge. Written reports coming from lessons learned and impressions from experiences are examples of externalization. In combination mode, dynamic knowledge is gained by pooling isolated and existing pieces of explicit knowledge into a holistic system structure. The final mode of spiral is internalization, where individuals absorb this new explicit knowledge. Explicit knowledge is applied multiple times, enriching the tacit knowledge base by including it in

habits and daily routines. The knowledge creation cycle continues along the spiral and jumps from the individual level to the organizational level when tacit knowledge is exchanged again. The SECI modes must be supported by two other elements—'ba' and knowledge assets—to realize knowledge creation as shown in [Fig. 3](#) ([Nonaka et al., 2000](#)).

3.2. 'ba'

Knowledge creation or sharing cannot occur in a vacuum, instead depends on the method of participation and the individuals who participate. The Japanese philosopher Kitaro Nishida introduced the 'ba' concept and Shimizu later refined it. The Japanese word 'ba' refers to a specific time–space nexus, and conceptually unifies physical space, virtual space, and mental space such as an office space, e-mail, and shared ideals. 'ba' means the place, and in current jargon it is the zone that actively supports simultaneous and spontaneous interaction in parts or in whole for knowledge creation. It also provides a shared context for the meaningful existence of knowledge and bridges the gap with information ([Nonaka et al., 2000](#)). The context changes the meaning of knowledge, when shared or interpreted for a purpose. The shared context or place can be tangible, intangible, or a combination of both to create and utilize the knowledge. Commitment to spend time and energy on events as well as in activities and interactions in 'ba' is very important for knowledge creation.

Interaction level (individual or group) and media type (face-to-face or virtual) result in four types of 'ba': originating, dialoguing, systemizing, and exercising ([Nonaka et al., 2000](#)). In originating 'ba', individuals share experiences and feelings face-to-face. Dialoguing 'ba' is helpful in promoting face-to-face interactions among group participants. Systemizing 'ba' offers a combination of explicit knowledge in virtual space through a group interaction. The members participate and engage in various 'ba' to develop a shared sense of purpose by interacting with each other, and transcend one's limited and subjective perspective to create knowledge ([Nonaka et al., 2000](#)). The individual's interaction in virtual space falls under the category of exercising 'ba.' 'ba' lays a foundation of four SECI modes for informal, simultaneous, and dialectical dialogues among individuals and/or a group in physical and virtual space, as shown in [Fig. 3](#).

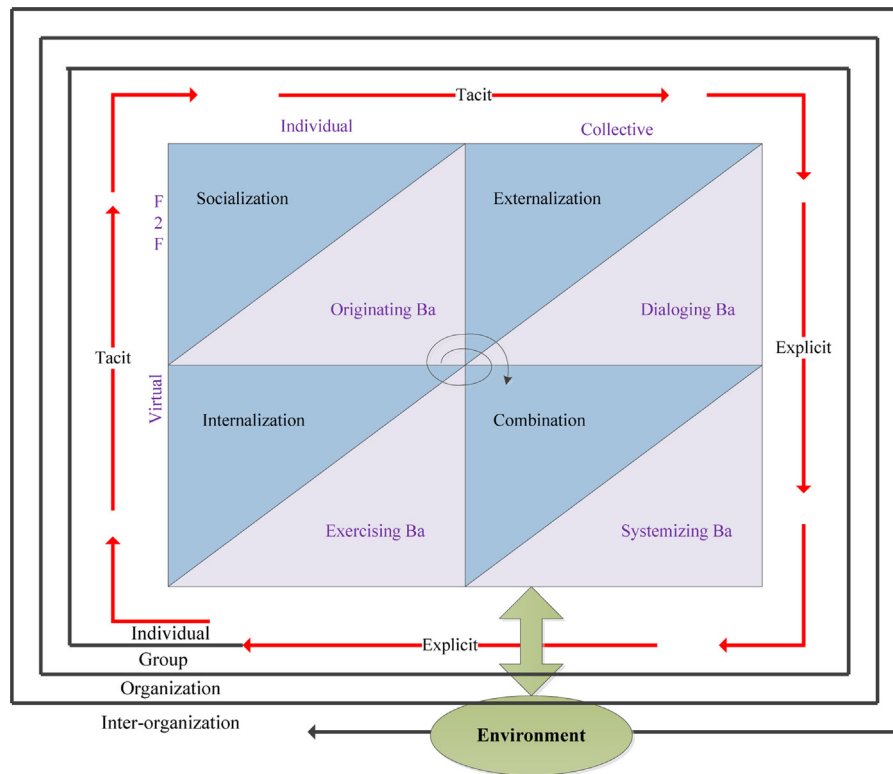


Fig. 3. Integrated dynamic knowledge model in a spiral form (Nonaka et al., 2000).

3.3. Knowledge assets

The knowledge assets depend heavily on the strategic orientation of a firm and the characteristics of ‘ba.’ They are intangible firm-specific resources such as inputs or outputs of the knowledge creation process that contribute in yielding value. Existing know-how skills, patents, and technologies are in the category of already acquired knowledge assets. They have received a lot of attention due to their tangible attributes and relative ease in measurement. However, knowledge creation is an organizational capability and a source of innovation that needs attention (Nonaka et al., 2000). A specific way of doing things is reflected in one of the most important knowledge assets termed “kata.” It consists of three simple steps: shu (learn), ha (break), and ri (create), which is a dynamic thinking pattern intended to create a self-renewal process. The thinking pattern of the firm is a continuous process changing obsolete sources of knowledge to new ones for a successful future. Such knowledge assets cannot be evaluated and managed effectively, owing to the lack of effective systems and tools. It is nearly impossible to buy or sell the organizational knowledge assets, so they must be built within. A high level snapshot of presently owned all knowledge assets will not be enough for managing them properly in the future. Therefore, Nonaka et al. (2000) divided knowledge assets into four types: experiential, conceptual, systemic, and routine, in order to understand how knowledge assets are created, acquired, and exploited. The next section highlights the role of lean thinking in product development.

4. Lean thinking in product development

The Toyota Production System built on lean thinking is the most successful disruptive innovation after Ford’s River Rouge plant (Ohno, 1988). The term “lean thinking” was first coined by Womack, Jones, and Roos (1990) in their famous book “*The Machine That Changed the World*.” Later, Womack and Jones (2003) proposed

Table 1

Inherent difference between manufacturing and engineering in terms of lean principles (McManus, 2005).

Lean Principle	Manufacturing/production	Engineering
Value	Visible at each step, defined goal	Harder to see, emergent goals
Value stream Flow	Parts and material Iterations are waste	Information and knowledge Planned iterations must be efficient
Pull Perfection	Driven by takt-time Process repeatable without errors	Driven by needs of enterprise Process enables enterprise improvement

the five lean principles, which are (1) specify value, (2) identify the value stream and eliminate waste, (3) make the value flow, (4) let the customer pull (value), and (5) pursue perfection. In essence, leanness mainly depends on one critical starting point called “value” that can be defined only by the customers. Hence, lean tools and methods primarily focus on exploring ways to identify and eliminate the seven deadly wastes that add no value for a customer or an organization (Cai, Tyagi, & Yang, 2011; Liker, 2004). Their implementation, particularly within manufacturing operations has turned out to be an enduring domain of earlier research (Khalil & Stockton, 2010). McManus (2005) stated that a tested theory that puts lean thinking into the heart of a holistic system and has the ability to extend across other elements of an enterprise, such as product development, is still rarely mentioned in the literature. This is owing to the inherent differences between manufacturing and product development. Therefore, it is worthwhile to compare the two to notice the distinctions (see Table 1). For example, in the former, loopsbacks are associated with wastes and considered to be a diminishing contribution; however in the latter, loopsbacks could be associated with gaining important dynamic knowledge. Hence, direct implementation of lean principles from manufacturing to

product development is questionable and full of doubts (Radeka, 2012).

This gap has been identified as a potential area of research by a number of authors. Morgan and Liker (2006) and Ward (2007) provided different perspectives to compare manufacturing and product development and stressed that lean tools and methods have the ability to be modified appropriately to work well in the latter. For example, in manufacturing the “pull” principle focuses on eliminating overproduction of material. This is done by maintaining a balance in demand from downstream activities to supply of upstream activities using signals adding a value for the end-customer. Similarly in product development, knowledge is pulled/created to get the right information to the right person at the right time. Most lean tools and methods inherently support knowledge creation in one or multiple SECI modes. Generally, organizations tend to neglect the long-term benefits as they target only such short-term benefits of bringing products to the market faster (Kennedy et al., 2008). Morgan and Liker (2006) mentioned several lean tools and methods for standardization and visual communication that can also assist effective and powerful knowledge creation. Organizations are required to adapt those tools and methods to fit their people and specific culture. Moreover, tools and methods that support knowledge creation are not necessarily lean, so this research also introduces some non-lean tools and attempts to integrate them in the daily work. It helps employees to accept their implementation with higher efficiency and enthusiasm. The next section describes the methodology used in this research.

5. Research methodology

There are seven different perspectives in understanding LPD: performance analysis, decision-making, process-modelling, strategy development, supplier partnership, lean manufacturing, and knowledge networks (Martinez Leon & Farris, 2011). In knowledge networks, generally, the SECI model (Nonaka, 1994) has been exploited to develop knowledge-related research frameworks. However, important points like input/output of a SECI mode or physical/virtual space where the knowledge is created or shared have been neglected. In order to tackle this, an integrated dynamic knowledge model proposed by Nonaka et al. (2000) that is comprised of three elements: SECI modes, ‘ba’ and knowledge assets, is targeted. This model is adopted since it is the most advanced model that clearly exemplifies how knowledge is created in practical settings. This article discusses the implementation of ten lean tools and methods in the integrated model to enhance the efficiency of knowledge creation in a product development domain. In the literature, researchers and practitioners have identified, analyzed and documented a large number of lean tools, methods, and techniques based on the Toyota Production System. For authors, it is important to understand how they can specifically address the needs of knowledge creation. The key is in picking the right mix and integrating them into the strategy to deliver the most value; otherwise they will end up resulting in a lot of waste. Experts like Ward (2007), Morgan and Liker (2006), Kennedy et al. (2008) and other relevant research papers in the literature agreed upon 21 LPD enablers. All of them can be considered as the ingredients of the LPD framework. Among the 21 agreed-upon LPD enablers, however, this paper proposes a set of 10 lean tools and methods, which fit for implementation in the integrated dynamic knowledge model. These items were selected based on a consensus of researchers and practitioners known for their expertise and experience in the product development domain. These tools and methods are: (1) apprenticeship, (2) employee cross-training, (3) the chief engineer, (4) set-based concurrent engineering, (5) trade-off curves, (6) visual tools, (7) check sheets, (8) scrum, (9) PDCA, and (10) the 5 whys.

In Section 6 below, each of them is analyzed and appropriately positioned in a SECI mode depending on their best fit and support for knowledge creation. The rationale behind selecting an appropriate SECI mode for each lean tool/method along with potential ‘ba’ and knowledge assets is explained later in the implementation analysis section. Concentrating on deploying a large number of lean concepts can result in negative feedback from employees in terms of utilization. This is due to the fact that employees have to possess (or learn) an adequate understanding of each concept and a large number of lean tools can draw less interest and lack of usage, which can lead to their banishment in the future. So the optimal number of lean tools/methods should be enforced to realize the maximum benefits. Once those tools/methods are implemented, gradual and continuous improvements should occur in them. At the same time an organization should explore, develop, and encourage more tools/methods. In the next section, each of them is briefly introduced to keep up with the objective of this paper.

6. Implementation analysis

Two branches of research are theoretical analysis and empirical analysis, and the order in which they are linked with each other defines two research strategy types. The deductive strategy that focuses on “theory–then–research,” and the inductive strategy that follows “research–then–theory,” have been recognized in the literature as appropriate (Yin, 2009). This paper employs a deductive strategy in analysing lean tools/methods to support efficient knowledge creation and bridge the research gap. An overview of the analysis is as follows. For *Socialization*, apprenticeship, informal meetings, and employee cross-training are discussed. Under *Externalization*, the chief engineer, set-based concurrent engineering, and trade-off curves are analyzed. For *Combination*, two visual tools (A3 reports and spaghetti diagrams) are explored. For *Internalization*, two visual tools (A3 reports and virtual obeya) and the use of check sheets are discussed. Finally, three tools: Scrum, PDCA, and the 5 whys, are shown to support knowledge creation in all modes.

6.1. Socialization mode

According to Oshri, Kotlarsky, and Willcocks (2007), the socialization mode offers an opportunity for experience sharing to create tacit knowledge and improve collaboration throughout a project life-cycle. It encourages individuals to spend time together in joint hands-on experiences, informal meetings, and work in the same environment to exchange personal or specialized knowledge (Li, Huang, & Tsai, 2009). Socialization requires the trust, respect, and mutual understanding among resources during the course of communication. This helps in combining a comprehensive form of tacit knowledge to enrich ‘sympathized knowledge,’ such as an intellectual model and technological expertise (Nonaka & Takeuchi, 1995). The required ‘ba’ for the socialization mode is face-to-face interaction locations, video conferencing tools, and virtual reality tools. The shared context of learning from apprentice and coaching from the leader is another required ‘ba’ for successful knowledge creation. The knowledge assets for socialization mode are know-how and skills possessed by individual employees regarding the current products, processes, customers, suppliers etc.

6.1.1. Apprenticeship

Apprenticeship goes against the orthodox approach that believes in ‘command and control’ (Evered & Selman, 1989). The traditional way of micromanagement does not offer an ambience conducive to gaining tacit knowledge, and thus does not help either the coach or the apprentice. On the contrary, lean thinking encourages a leader to patiently coach the apprentice who learns by doing

under his/her direct supervision. This is due to the fact that mentors (leaders) naturally possess a vast amount of experience in the form of tacit knowledge, and are experts in their domain (Verma, Tyagi, & Yang, 2014). Apprenticeship requires a strong desire to communicate and interact with others by engaging in day-to-day hands-on activities. Adoption of this approach can influence how a company allows individuals to share experiences, intuitions, observations, and imitations. For example, in Toyota a new employee is assigned to a leader who works with the junior employee as a mentor for strict training and development. New employees are advised to do their jobs under the guidance of a leader to focus on methods rather than results and learn them (Morgan & Liker, 2006). In the game of cricket, the Australian Cricket Board management has assigned individual current cricketers with former expert players based on talent and abilities. It helps an individual player to hone skills under proper guidance. This is another example of apprenticeship and exemplifies the interpersonal creation of tacit knowledge through socialization.

6.1.2. Informal social activities

Encouraging social activities outside the work place for direct and face-to-face communication empowers teams to gain new insights. Leonard and Sensiper (1998) stated that comfortable communication of tacit knowledge is only possible if there is a mutual trust and understanding. They are nurtured by facilitation of social interaction and networking. Organizations should initiate and encourage informal internal events providing an extended interaction for employees to share ideas and perspectives. Social interactions among individuals lead to more accurate interpretations, as compared to when individuals decipher information alone (Alavi & Leidner, 2001; Tyagi, Yang, Tyagi, & Dwivedi, 2011; Tyagi, Yang, Tyagi, & Verma, 2012). Establishing such dialogues can pave the way for improved performance of the development projects.

6.1.3. Employee cross-training

Most organizations have already recognized that employees are their most important assets. Investment to augment the capabilities of an asset is important, and leadership must promote, encourage, and actually become involved in this. Training and education to bring deliberate changes is the primary driving force for dynamic knowledge that benefits both employer and employee. Such training helps a team member to perform a wide range of activities enhancing flexibility and greater idea generation capabilities. Employees with greater flexibility and capability can open a new horizon for an organization to offer quality products and services. On the other hand, for employees cross-training provides an opportunity to gain dynamic knowledge and skills, increasing their value, positively impacting their confidence. It also helps the employees to attain enrichment and enlargement in terms of their jobs.

Other potential methods that can likely improve knowledge creation during the socialization mode are involving cross-functional teams in joint projects, arranging meetings, seminars, and training workshops, lunch and learn sessions with other departments, inviting qualified members and external experts to speak about their beliefs, values, and culture, and providing a common place for lunch breaks or other activities, technical speed dating, monthly cascade meetings etc.

6.2. Externalization mode

Researchers are still trying to identify the key influencers, which can mitigate the difficulties of the socialization mode. This shifts the focus towards externalization, where best practices and lessons learned are documented to avoid high uncertainty in future innovation (Gold, Malhotra, & Segars, 2001). Knowledge is created

when existing knowledge is changed from the tacit to explicit form (Choi & Lee, 2002). During this mode, the know-how knowledge is exposed in the form of concepts, hypotheses, metaphors, analogies, and models for explaining in more tangible and generic forms through demonstration, comparison, and experimentation (Salmador & Bueno, 2007). An organization pushes externalization to create conceptual knowledge and convert abstract ideas into a concrete form of information through text and symbols. A high commitment and participation of internal qualified members and external experts in the training programmes and seminars with little external control (little pressure from shareholders) are required for successful completion of externalization. Open dialogue among employees and senior leadership who are seeking honest feedback is a strong motivation for reducing ambiguities. The potential 'ba' for externalization are interview rooms, Microsoft productivity tools such as Word and PowerPoint, tools to capture processes, expert systems, discussion platforms such as meeting rooms, and reflective peer-to-peer networks. The knowledge assets are images, languages and symbols of product concepts, designs, and brand equity.

6.2.1. Chief engineer

The Chief Engineer (CE) is one of the most important lean methods. This position acts as a "heavyweight project manager" who exerts the total responsibility for multiple development projects to timely drive them with a view to achieve aggressive targets (Morgan & Liker, 2006). In addition to the development projects, the CE puts forth strenuous efforts to understand customer values and needs during the socialization mode (Ward, 2007). Morgan and Liker (2006) also emphasized that the CE is someone who promotes knowledge externalization. Once the needs of the customer are understood, the CE communicates them through concept papers and other communication approaches to other team members. In such papers, the CE externalizes the tacit knowledge in the form of explicit knowledge; thus, allowing others to obtain and grasp it and act upon it.

6.2.2. Set-based concurrent engineering (SBCE)

SBCE encourages designers to consider a broad range of potential alternative concepts in the beginning, instead of a single solution as in point-based engineering. Cross-functional teams including market analysis, design, development, testing, and manufacturing contribute by providing information in parallel to help develop alternative design concepts (Shah, Soni, and Patel (2013). Subsequently, concepts converge by deleting weak design attributes until a superior solution is found. The objective is to eliminate waste early in the product design process so that the need for costly design and engineering changes at the back-end is minimized. Fundamentally, starting with a set of design alternatives instead of a single design assists in avoiding iterations and large amounts of rework. SBCE helps the externalization mode by capturing knowledge such as design rules from engineers and systematic evaluation of the development process. Dynamic knowledge can be stored or manipulated and can be transferred to others for future reuse. In order to investigate SBCE, Liker (2004) pointed out the example of the development of a new suspension for the Prius car at Toyota. Toyota held a competition and got around 20 potential suspension designs to evaluate and test simultaneously, instead of using trial and error to modify a single design, to minimize the total cost of development.

6.2.3. Trade-off curves

Trade-off curves, considered to be a cornerstone of the externalization mode, are simple graphical representations to demonstrate the change of performance of output (X) against one or more parameters (Y). The example includes estimation of key parameters such

as diameter and wall thickness of a pipe (design decisions) to match customer requirements of fluid pressure and velocity (Tyagi, Ghorpade, Karunakaran, & Tiwari, 2007). Such curves embody explicit knowledge generated during tests and can be used in future endeavours. Succinct trade-off curves facilitate codification and generalization of knowledge of quality issues in order to avoid them in the future. Toyota heavily relies on extensive prototyping during product development to successfully develop and release new models of a car in record-breaking time. Toyota spends a considerable amount of time and effort to develop the trade-off curves from the analysis of prototyping data. Such test data analysis knowledge in form of trade-off curves provides the ongoing knowledge for future projects, and, thus, reduces redundancy. The employees externalize the tacit knowledge through a trade-off curve when knowledge is articulated in the form of documents or experience reports. This knowledge generated through the trade-off curves is quite useful in creating standards and making intelligent decisions.

Other methods to foster externalization are conducting experience workshops, expert interviews, and experience reports. The objective of experience workshops is to take a retrospective view to share important aspects and take away learned lessons, exchange of experiences, and to judge the project's success (or lack of success) for subsequent projects. An outside project facilitator should ask the important questions related to the objective of the project, achievements, successes/failure, and how to use this knowledge in the future. Activities that report the beliefs, values, experiences, and culture of internal and external experts are especially encouraged. However, eliciting, codifying, and transforming the Subject Matter Expert's (SMEs) knowledge into a sharable format is a painstaking task owing to dynamic attributes and the subjective nature of knowledge.

6.3. Combination mode

Time spent by SMEs on project oriented tasks is more valuable than writing reports (Tyagi, Yang, & Verma, 2013). In addition, tight schedules make knowledge creation difficult in the externalization mode so manual knowledge compilation or other appropriate methods are important. In order to maintain expertise or technological knowledge for a longer period at the enterprise level, another knowledge creation mode seems essential. Collected reports issued by the internal and external agents (e.g., customers, competitors, partners, or government representatives) are integrated, classified, reclassified, and synthesized with various existing explicit notions possessed by employees, to form a cluster of organized knowledge resulting in 'systemic explicit knowledge'. In this mode explicit knowledge mentioned in files, databases, networks, and reports is classified and transformed into intricate and organized explicit knowledge to identify innovative products or technologies most likely applicable to be put into practice. The potential 'ba' for the combination mode would include tools for systematizing knowledge, tools for collaborative computing, web forums, best practices databases, lists for discussion, and the intranet. The knowledge assets are systemized and packed documentation, manuals, specifications, database, patents and licenses.

6.3.1. Visual tools

Visual tool boards are a powerful way to create knowledge during the combination mode. A3 reports and spaghetti diagrams are two main examples of visual tools considered in this research. An A3 report is a single piece of A3 size paper that contains graphs and visual representations instead of large amounts of text. Engineers synthesize, distill, and visualize the knowledge to put a large amount of both tacit and explicit knowledge into compressed form (Sobek & Smalley, 2008). The A3 report epitomizes the old adage,

"one picture is worth 1000 words", and makes it easy for the user to comprehend the information. It helps in integrating and combining old explicit knowledge with new explicit knowledge, and, thus, belongs to the combination mode.

A spaghetti diagram is a tool that indicates the value added and non-value added workflows using a continuous line in a visual flow chart format. Traditionally, the lines are hand drawn and follow the observed workflow. These lines may not be to the exact scale of the actual process. This is because the intention of the tool is to depict the flow of work or material in order to identify and eliminate any non-value-added movements. Improved knowledge creation in combination mode is supported by creative applications of computerized communication networks and large scale databases (Nonaka & Takeuchi, 1995). These activities should be integrated with the deployment of good and proven practices or procedures; updating of files, databases and websites; inclusion of relevant published research; and new policy development reports. It becomes a powerful tool when it is used with 5S initiatives (5S refers to a workplace organizational methodology based on: sort, systematize, shine, standardize, and sustain). The collected information should be referenced when developing rules, reports for decision-making.

Other practices that can be helpful in combination mode are project briefings, knowledge brokers, databases, and selection of best practices. Project briefings can aid by involving the experienced team to provide knowledge and documents containing issues/results from previous projects. The new requirements can be combined with this knowledge by the current team. Generally, best practices can be considered as explicit knowledge if they are noted. They are proven approaches to handle repeating problems or processes effectively, and the documented information should be regarded as the major source of communications. Hence, functional specifications of new projects coupled with explicate experiences or documents from prior projects results in concrete knowledge creation during the SECI combination mode.

6.4. Internalization mode

In defining the internalization mode, Vaccaro, Veloso, and Brusoni (2009) state that dynamic knowledge occurs when collective explicit knowledge is transformed into tacit knowledge, updating the mental representations of individual organization members. This is generally achieved both by accessing the organization database and intranet to obtain required information, and by analysing deliverables of training programmes, workshops, seminars, and conferences. Such tuned-up, combined, and structured explicit knowledge leads towards action-oriented knowledge intended to be disseminated for pragmatic use. Analysis and explanation of relevant reports issued by suppliers, competitors, partners, or government representatives can be used during the knowledge internalization mode. This mode witnesses a functional and realistic outcome for organizational performance improvement and, thus, becomes an important stage in the SECI. Researchers also acknowledged that if deliberate knowledge creation and transfer among partners becomes costly and tedious due to knowledge stickiness, then it can have negative impacts towards internalization (Li & Hsieh, 2009). The potential 'ba' for the internalization mode includes collaborative knowledge networks, neural networks, and notes databases. The knowledge assets are the organizational culture, organizational routines, and the know-how of daily operations embedded in actions and practices.

6.4.1. A3 reports

A3 reports also support internalization by facilitating transformation of explicit knowledge into tacit when used as a tool for solving problems. The issues can be discussed easily if A3 reports

Table 2
List of lean tool/method supporting the knowledge generated in SECI modes.

Tool/method	S	E	C	I	'ba'	Knowledge assets
1. Apprenticeship	X				Face-to-face interaction locations, video conferencing tools, and virtual reality tools	Know-how and skills possessed by individual employees regarding current product, process, customer, supplier etc.
2. Employee cross-training	X					Images, languages and symbols of product concepts, designs and brand equity
3. Chief engineer		X			Interview rooms, tools to capture process, expert systems, discussion platforms such as meeting rooms, and reflective peer to peer networks	
4. Set-based concurrent engineering		X				
5. Trade-off curves		X				
6. Visual tools					Tools for systematic knowledge, tools for collaborative computing, web forums, best practices database, list for discussion, intranet	Systemized and packed documentation, manuals, specifications, database, patents and licenses
6.1 A3		X	X	X		
6.2 Spaghetti diagram			X			
6.3 i-Obeya				X	Collaborative knowledge networks, neural networks and notes database	Organizational culture, organizational routines, know-how of daily operations embedded in actions and practices.
7. Checksheets				X		Individual or combination of above stated assets, depending on the mode.
8. Scrum	X	X	X	X	Individual or Combination of above stated 'ba', depending on the mode.	
9. PDCA	X	X	X	X		
10. 5 Why's	X	X	X	X		

are hung on the wall of “Obeya rooms,” or wherever the meetings occur. This can be used to explain the content of related reports or documents to shape the organizational culture and point-of-view based on the available data and information [Verma, Shukla, Tyagi, and Mishra \(2014\)](#). It provides a platform for effective and timely communication to reduce waiting time for decision making. A3 reports can act as a medium to demonstrate models and/or concepts using a standard report template for knowledge externalization. Expert interviews are conducted to articulate tacit knowledge pieces in the form of written documents, which mainly contain the staff point-of-views on projects and strategies. These reports contain the results of negotiation with customers, partners, and others based on cumulated experience, and findings of meetings, seminars, workshops, conferences, and training programmes.

6.4.2. Virtual obeya

There is a scarcity of visual control systems for integrated planning and scheduling of work that are transparent enough for making real-time decisions. It gets worse when geographically distributed teams are involved. “Obeya” is a planning and communication tool, which roughly means “big room” in English. Each team works in a physical Obeya room and regularly collaborates with other multi-disciplinary teams. Teams ‘see’ the process and know where and when actions need to be completed, and where problems may arise. Virtual obeya uses a digital board for enhanced collaborative work that virtually displays current status at remote locations to focus on problem solving and coordinating actions ([Blankenburg, Kristensen, Aasland, & Sivertsen, 2013](#)). Responsible representatives of various functional specialties maintain the room to support effective and timely communication across multiple locations at the same time. This interactive involvement of geographically dispersed cross-functional teams effectively controls and manages a project as compared to SMEs at only one location. Virtual obeya serves multiple purposes including real time knowledge creation with coordinated efforts, on-the-spot fast and accurate decision making by involving the right players at one place. This enables easier delegation through full visualization of the work to be performed, clearer roles and responsibilities, and a sense of team integration.

6.4.3. Checksheets

Checksheets are used to put the available knowledge on a sheet of paper in the standardized form to provide a better review basis for decision-making ([Kennedy et al., 2008](#)). Checksheets are a medium to put explicit knowledge in a written form for future reuse. Toyota regularly uses them to review all design decisions and ensure a minimum quality level. They act as a reminder to

remember important things and are regularly updated and used. They are beneficial in improving the documentation of information, design decisions, and knowledge reuse. They facilitate documentation and visualization to increase the knowledge base and knowledge sharing, thus knowledge internalization occurs.

6.5. Tools that supports knowledge creation in four SECI modes

6.5.1. Scrum

This sub-section provides a discussion on how knowledge is created through “Scrum,” and the importance of enabling ‘ba’. A scrum team consists of at least three roles: a product owner, who represents the voice of the customer; a cross-functional development team, which actually creates shippable increments of the final product, and the scrum master, who keeps the scrum process moving and who removes impediments that are preventing the development team from delivering their products. Scrum enables fast feedback, since teams execute steps in smaller cycles for continuous improvements. The scrum team interacts iteratively to become hyper-productive and stabilize the environment where the team works. This environment is the scrum team’s ‘ba’, which must be created and transformed continuously with a view to achieve the most from it ([Sutherland, Schoonheim, Kumar, Pandey, & Vishal, 2009](#)). A scrum master should facilitate the scrum process. It is the duty of the scrum master to provide the platform to create and maintain the flow of knowledge in ‘ba’. All SECI modes are present in scrum. The daily scrum meeting supports the occurrence of socialization and combination modes, given the dynamics created by having the scrum team always working together to solve problems. Additionally the technical part of the post-scrum review also supports both modes. The originating and cyber ‘ba’ are the scrum team’s location. The required documentation depends on what the team or scrum master select that supports externalization. The team and individual members gain knowledge in short cycles of sprint and scrum ceremonies to support internalization and ultimately result in development.

6.5.2. Plan–Do–Check–Act cycle

The four steps of continuous improvement: Plan, Do, Check, and Act, can be viewed as the counterparts of the four SECI modes. The Plan step corresponds to socialization since there is an interaction to clearly explore the customer’s objectives and the methods required to achieve those objectives. The Do step is similar to externalization when an improvement team tests solutions to the problem at hand and dynamic knowledge is generated in forms of reports, tools, and manuals. Trade-off diagrams and set-based concurrent engineering tools are generally used to conduct the testing

to find the optimal solution. Thereafter, appropriate actions when knowledge is combined with existing knowledge to create knowledge ensure the success of Check-step. The Act step requires taking actions and implementing suggestions for improvements, resulting in internalization of explicit knowledge.

6.5.3. 5 Whys

The 5 Whys is a systematic approach to get to the root cause of a problem. In this approach, questions are asked generally 5 times to get down to the bottom of the problem in understanding cause/effect relationships. It should be the practice of employees to ask questions in order to determine the ultimate root cause of a defect or problem. This is one of the most powerful and simple methods to access the tacit knowledge embodied in the employees' minds, and to generate explicit knowledge in the documents and reports. Hence, it can be used to support knowledge creation in all SECI modes. A summary of the ten lean tools and methods, which support SECI modes, along with corresponding 'ba' and knowledge assets, is provided in Table 2.

7. Conclusion and future research

Dynamic knowledge paves the way for innovation and, thus, contributes to the growth of an organization. In order to describe a practical knowledge creation process, an integrated dynamic knowledge model made up of SECI modes, 'ba', and knowledge assets has been targeted. With a view towards improving the efficiency of the knowledge creation process in this model, a set of ten lean tools and methods is presented in this paper. Efficient knowledge creation not only decreases the magnitude of knowledge gaps, and assists future projects to start from a higher level of knowledge but also helps in making the right decisions quickly for faster and improved quality products. It also assists in reducing costly rework at the back end of the process by creating knowledge at the right time and right place. It is also stressed that simply implementing lean tools and methods is not the ideal solution for their sustainment and effective utilization, rather a strong lean mindset that fits into the organizational culture is important. Additionally, successful implementation requires organization-wide changes to systems, practices, and behaviours. One of the findings of this analysis is that Scrum, PDCA, and the 5 Whys can fit and support knowledge creation in more than one SECI modes.

In essence, the article investigated how lean tools and methods can facilitate efficient knowledge creation for the organizational learning. The development of an evaluation model to estimate the improvements in product development performance resulting from knowledge creation or ranking of SECI modes on a specific product development phase is a topic of future research.

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