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# THE LEAN PRODUCT DEVELOPMENT: AN APPLICATION TO REFRIGERATION INDUSTRY

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**Abstract.** *Lean in a product development environment enhances integration among developers as it reduces development risks and promotes innovation and knowledge management. However, its application in research environments dedicated to the development of innovative products, where integration is a crucial factor and the development risks are high, has not been reported in the literature. Models and frameworks for lean product development (LPD) available in the literature provide the basic elements and steps necessary for its implementation, but a guide on how to put it into practice in a research and innovative environment is still missing. Therefore, this paper intends to fulfill this gap by proposing a LPD model for an innovative product in a research environment. The proposed model is based on the Toyota Kata approach to promote integration between the developers and create an innovation environment. The model was implemented in an action research project to develop a compact magnetic refrigerator. As a result, intensive integration was promoted between the subsystems have risen substantially since the model was implemented into the research environment and the development team has improved its alignment and focus on the product value already after the first phase of the implementation. In addition, the rework has decreased and an improvement in the knowledge management was verified. The implemented model has resulted in an improvement of the deliverables quality and the risks associated to the development of the innovative products have decreased.*

**Keywords:** *lean product development, Toyota Kata, innovative product development, magnetic refrigeration, quality function deployment*

## 1. INTRODUCTION

Lean product development (LPD) is the application of lean thinking in the product development environment (Haque and James-Moore, 2004; Wang *et al.*, 2011; Leon and Farris, 2011). The strategy of possible project solutions convergence in LPD is known as set-based concurrent engineering (SBCE). The benefits of adopting LPD and SBCE are related to innovation, rework reduction and increase in value adding during the product development process. There are potential benefits in adopting LPD in the generation of transformative technologies (Morgan and Liker, 2006). A successful development of an innovative product is based on flexibility, scientific research and knowledge sharing. Toyota Kata allows continuous improvement of product development through routines based on scientific method.

Thus, by promoting knowledge sharing and visual communication, it has potential to be an excellent approach to increase the level of innovation and reduce risks in the research project (Rother, 2010).

Although some works have outlined the steps necessary to implement LPD in an industrial environment (Wang et al., 2011), none has demonstrated how the implementation should be carried out. Based on this scenario, this paper aims to demonstrate some preliminary results on the implementation of a LPD model using the Toyota Kata approach (de Oliveira, 2017). Additionally, guidelines are offered on how to conduct a LPD implementation. To demonstrate the benefits of the proposed model, an action investigation was performed in a research project developing an innovative product: a compact magnetic refrigerator.

## 2. THEORETICAL BACKGROUND

LPD is a term used to describe the Toyota method of product development and its principles and practices. LPD has demonstrated reduction in costs, quicker development times and higher quality than other product development approaches (Leon and Farris, 2011). The LPD strategy for product concept convergence is known as Set Based Concurrent Engineering (SBCE). This strategy consists of a narrowing process that progressively eliminates solutions or concepts which fall short of pre-defined customer requirements. All concepts are developed concomitantly until the team is sure that it can be discarded. The elimination process advances until only one possible (final) design concept remains. The narrowing process evolves as a result of comparisons of alternatives against customer requirements, compatibility between the subsystems of the product, and by using trade-off curves.

To successfully implement the SBCE, the product and the development team must be divided into groups (subsystems) and the value of the product must be deployed. This value dictates the narrowing process for the SBCE. Each subsystem proposes their own set of possible design solutions for their subsystem. Then, in the so-called integration events, the subsystem compares their solutions to verify their compatibility. Subsystem concepts that cannot be integrated are discarded. Trade-off curves are constructed for each subsystem, and are used to identify which solutions meet the customer requirements.

During implementation, lean techniques and tools are incorporated above thinking and action routines. Thus, by constantly repeating the Toyota Kata behavior, designers can train their skills and learn about their process and themselves (Rother, 2010). The Toyota Kata approach is based on the PDCA (Plan – Do – Control – Act) scientific method and on a routine that establishes the roles of Coach and Learner. The Learner is a person who is looking into reaching a particular goal, improving a process, and achieving a better condition. The Coach is a person who has the ability to guide and help the Learner through the improvement process.

The Toyota Kata can be divided in two complementary routines: The Improvement Kata and the Coaching Kata. The Coach guides the Learner through the coaching Kata, and the Learner works on the problem through the Improvement Kata, as shown in Fig. 1.

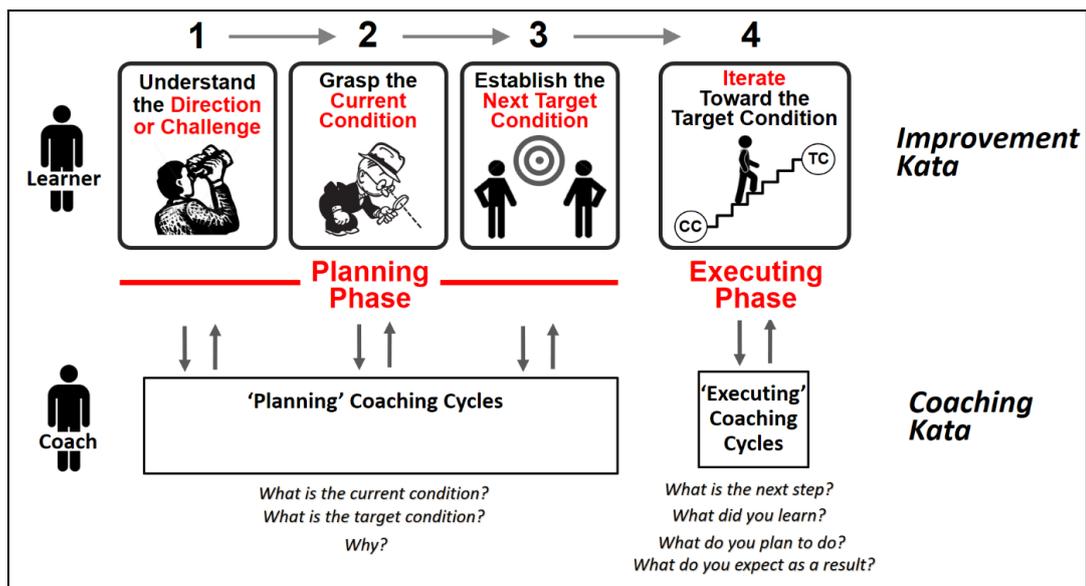


Figure 1. Improvement and Coaching Kata. Adapted from Rother (2010).

The Improvement Kata consists of four basic steps, repeated by the Learner in order to fulfill a major goal or the so-called Kata challenge. This challenge is defined by the Learner with help from the coach. First, the Learner is required to understand the challenge. Next, the Learner must grasp the current condition of the process. Based on the gap

between the current condition and the challenge, the Learner establishes an intermediary condition, known as target condition. The target condition is an intermediary status that must be achieved in order to complete the challenge. It is important to define consecutive target conditions toward the challenge — instead of just iterate to the challenge — as short goals facilitate controlling and learning about the process. When the Learner understands the current condition and knows the next target condition, short time cycles can be planned based on the PDCA, one at a time, in order to reach the target condition.

The Coaching Kata is a complementary routine that goes in parallel with the Improvement Kata. After each PDCA cycle completed by the Learner, the Coach makes a coaching session and asks six questions to assure that the Learner is acting in a scientific way: (i) “what did you do in the last cycle?”; (ii) “What did you expect?”; (iii) “What happened?”; (iv) “What did you learn?”; (v) “What do you plan to do in the next cycle?”; and (vi) “What do you expect as a result?”. This coaching session takes place in front of a storyboard, where the Learner records every step taken during the PDCA cycle, including the answers to those six questions.

### 3. A MODEL FOR LPD USING TOYOTA KATA APPROACH

The proposed LPD model proposed in an innovative product development consists of five different phases, as shown in Fig. 2 (de Oliveira, 2017). Each phase has its main activities and suggested tools to support them.

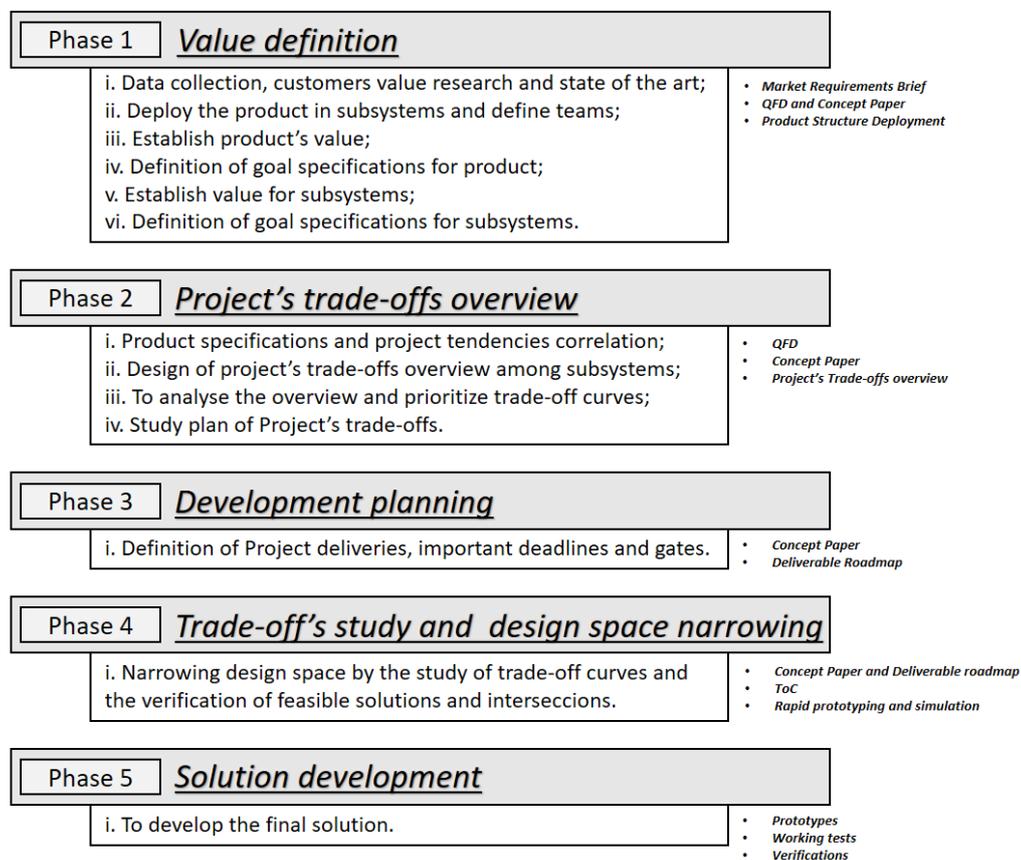


Figure 2. Proposed LPD model. Adapted from de Oliveira (2017).

The first phase focuses on the definition of the product value and the deployment of its subsystems. To develop the product, the development team must have a solid grasp on the value associated to the product. The value definition enables narrowing the design space, integrating the development team and providing a common language and value understanding. The results from this phase will guide all actions and decision making through all the remaining development phases. It is suggested that the development team uses the QFD (quality function deployment) form and the concept paper to define the value of the product and establish the development goals. This makes the management and communication between development teams easier.

The second phase consists in discussing and understanding the correlations between the development goals and the characteristics of the product. It is suggested that the development team use the roof of the QFD in this phase, as this is where these correlations are explicit. The development team must identify what are the trade-offs of the project and plan

on how and when to study them, in order to support the decision making of the project. In other words, knowing what the trade-offs are allows the teams to develop trade-off curves and narrow the design space by comparing the curves with the customer requirements and the design space of others subsystems.

The third phase consists in planning the project deliverables, integration events, milestones and checkpoints, in order to meet deadlines and the customer requirements. It is important to mention that, at the beginning of the product development, it is not possible to know exactly all the activities required in order to obtain the final product. Therefore, the plan proposed in this phase should not contain actions, but a definition of the main deliverables (what and when) so as to not compromise the deadline of the project. Next, each subsystem group must plan, for a short period of time, the activities required to meet those deliverables, in accordance with the cycles of the Toyota Kata. The chief engineer in charge of the project will make a decision, by observing the achievements of each subsystem and the deliverables plan, whether adjustments are necessary in order to achieve the goals and deadlines.

The narrowing process takes place during the fourth phase, by comparing the design space of each subsystem. Design alternatives that do not match customer requirements or are not compatible with solutions provided by the others subsystems are discarded. In this phase, the trade-off curves are especially important. When there is only one design alternative left for each subsystem, then the fifth phase starts, dealing with the integration of the solutions provided by each subsystem. The solution development phase is focused on the final product, and consists of tests to verify its functionality, adjust tolerances, etc. Due to the nature of the SBCE process, all subsystem solutions are compatible and easy to integrate. The Toyota Kata approach is used in the proposed model as presented in Fig. 3. This approach has several benefits but there are three main results associated with its use: reduce risks related to the design, visual and easy communication, stimulate innovation and the adoption of a scientific methodology.

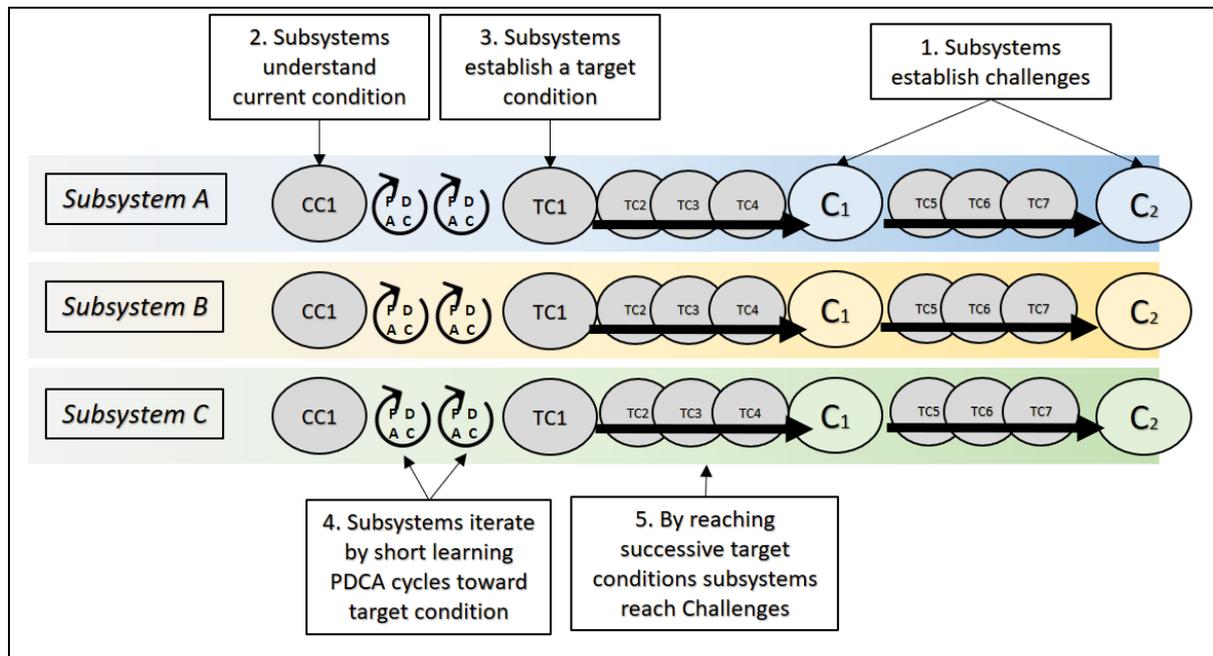


Figure 3. Toyota Kata approach for LPD

After the value definition established during the first phase of the proposed model, the development team is able to establish goals for the development process based on the customer requirements. These goals can be translated into Toyota Kata challenges, namely the final challenge, related to the final product, and intermediate challenges connected to important deliverables. By using the Toyota Kata approach, it is possible to iterate in short learning cycles until the team reaches the challenges established. Thus, by reaching successive targets, each subsystem can reach the final development challenge. This process reduces the risks frequently associated with product development, because it enables managers to foresee target conditions or challenges at risk of not being reached on time. In doing so, they can react in advance and provide more resources or make adjustments to the plan for the subsequent experimentation cycles. Furthermore, by using the Toyota Kata to connect the everyday activities of all developers to the challenges and target conditions, the chief engineer assures that all developers are integrated, focused and aligned to the value definition. Since the Toyota Kata approach provides a knowledge sharing structure through its learning cycles recording routine, it becomes easy to communicate the work and development from all subsystems. Yet the approach stimulates innovation and discovery by preconizing the scientific methodology and structured forms of studying problems and proposing solutions. The experimentation and learning steps of Toyota Kata induce the teams to go beyond and consolidate knowledge and record it for future projects.

#### 4. DEVELOPMENT OF A COMPACT MAGNETIC REFRIGERATOR

The proposed model was implemented in the Magnetic Refrigeration Research Group (PoloMag) of the POLO Laboratories at the Federal University of Santa Catarina (UFSC). The research group was composed of thirteen people (one academic principal investigator, one chief research engineer and eleven researchers). The chief engineer was chosen based on criteria of academic seniority and previous knowledge and experience. The goal of the project was to develop a compact magnetic refrigerator using the magnetocaloric effect. The product to be developed is an innovative product, because it is based on an emerging cooling technology. First, a plan was made to enable the implementation of the proposed model. Then, the research group was trained on the principles of LPD, Toyota Kata and was introduced to the proposed model. Finally, the product development and the researchers were divided in three subsystems: (i) active magnetic regenerator (AMR) and the magnet integrated design, (ii) hydraulic and control systems and (iii) cabinet and heat exchangers.

At the beginning of the first phase (value definition), a market research and the previously knowledge by the developers were used by the chief engineer to construct the first QFD matrix for the product, known as “the house of quality”. Based on the matrix of the product, each subsystem developed its own characteristics matrix to comply with the requirements described in the house of quality, which corresponds to the second order QFD matrices. Then, the QFD was analyzed and, together with more information about customers and competing technologies, the concept papers for the product and the subsystems were written. An integration event was held with all developers to discuss the outcomes of each subsystem and converge to an idea of the product and the resulting concept papers.

The second phase of the proposed model was implemented by having the subsystem groups analyzing the roofs of the QFD matrices in order to identify trade-offs associated with the product. This was carried out by comparing the product characteristics with their desired trends. At this point, the subsystem groups could know which trade-off curves (TOC) could be constructed in order to narrow the design space. Thus, a plan was set up to study the TOCs, which served, together with value definition, as base for the next phase, the development planning.

The third phase of the proposed model started with a draft of the deliverable roadmap, which is a timeline of development, where the chief engineer registered when the main deliverables should be accomplished. The main goals of product development were transformed into Kata challenges and were registered in the deliverable roadmap as well. This facilitated the comparison between challenges and deliverables, in addition to the verification if all registered deliverables led to the challenges accomplishment. Then, the chief engineer along with the developers made adjustments and detailed the deliverables in order to reduce development risks. Integration events were scheduled and registered on the roadmap. An integration event was held with all developers aiming to officially communicate the results of the planning and the deliverable roadmap and to start the development. The challenges defined for each subsystem served as a basis for the beginning of Kata cycles, when the subsystems experiment to reach target conditions begun.

The fourth phase initiated with a study of the TOCs and integration events to narrow the design space. Three integration events were monitored by the authors. The design space was already narrowed and the knowledge gaining provoked many iterations regarding the specification goals of the product. It was seen that the first characteristics stipulated for subsystems to define its design space were insufficient and they add new parameters for study.

#### 5. RESULTS AND DISCUSSION

It has been observed by the authors that the levels of integration between subsystems have risen substantially. This was due to the fact that the discussions and the participation of developers during integration events have improved. Furthermore, an increase in knowledge sharing on the project and development in each subsystem was observed. Developers reported that the access to important information became easier and they were able to know what the other subsystem groups were doing and how each would contribute to achieving the desired value in the final product value. The development team has improved its alignment and focus on the product value, especially through the development of the QFD (quality function deployment) and the corresponding concept papers. Many critical factors of the product were identified already during the first phase. For example, the refrigerator noise emerged as a critical request from the end user, and the hydraulic subsystem would be the most affected by this issue. Therefore, it was possible to verify the need of an acoustics specialist in the team during the development process to assure that the refrigerator would generate noise within the desirable specifications of the end user.

The deliverable roadmap enabled the development team to plan its activities through Kata cycles, with showed that this tool and Toyota Kata approach can work together in an efficient way. Using the Kata approach, an increase in integration and a better environment for discussion were created. In addition, there were improvements in knowledge management and sharing, since the developers could find the needed information easily than before the use of Toyota Kata. Yet, it became easy to understand the information recorded, since Toyota Kata has a clear pattern of six questions to record the experiments performed. The integration events, along with the TOC and value definition, enabled narrowing the subsystems design space, enabling SBCE. The developers’ knowledge gain has been improved and the

information has been gathered at the concept paper to better define the product, through new and more refined parameters. This reflects the alignment of the development team about the product value and the effectiveness of the proposed model.

## 6. CONCLUSIONS

The proposed model has shown to be effective to stimulate integration between subsystems and to reduce risks associated to the innovative product development. Furthermore, the model implementation has improved the knowledge management by using the Toyota Kata approach, which has been shown to be an effective methodology to manage the development of each product subsystem.

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## 8. RESPONSIBILITY NOTICE

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