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► To cite this version:

Masih Hanifi, Hicham Chibane, Rémy Houssin, Denis Cavallucci. Improving Inventive Design Methodology's Agility. 19th International TRIZ Future Conference (TFC), Oct 2019, Marrakesh, Morocco. pp.216-227, 10.1007/978-3-030-32497-1_18 . hal-02905551

HAL Id: hal-02905551

<https://inria.hal.science/hal-02905551>

Submitted on 23 Jul 2020

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Improving Inventive Design Methodology's agility

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Abstract. Inventive Design (ID) methodology has been developed in four main phases, from initial situation analysis to solution concept, in order to overcome TRIZ limitations. However, this methodology needs to optimize its performance, because it takes a lot of time to obtain the best solution concepts. In addition, the ability of ID to give the best result depends on individual knowledge and experience of designer, and correctness of initial situation analysis. The proposed methodology in this article uses a collection of tools and combines a long-term vision for continuous improvement. This improvement method focuses on removing the non-value added activities during the process and maximizing the quality of the results. Integration of this proposed methodology with ID framework will eliminate the wastes, which occur in different phases of ID method and increase its overall efficiency and agility.

Keywords: Inventive Design, TRIZ Methodology, Efficiency, Agility

1 Introduction

Ability of organization in innovating and introducing new high quality products at a quicker rate than competitors lead to success of any business. There is a clear evidence that increasing of efficiency, effectiveness and agility of innovation process, which is believed a bottleneck to new product introduction, is key to survival of the enterprises in the competitive global environment. This incites the companies to track continuously the methods and techniques more cost-effective and time-efficient to boost the performance. Among these methods, we choose to investigate Lean product development theory.

Lean Manufacturing theory was originated by Toyota Company in the early 1950s based on its product development process and make it to become one of world's leading car producer [1]. Nowadays, Many organizations have adapted lean in an attempt to reduce cost, decrease time, and maximize value in product development [2]. Where Lean Product Devolvement (LPD) is developed to be applied in design process. Lean philosophy takes a look at continuous eliminating nonvalue adding activities in order

to achieving the excellence, as well as inserting set of practices that help to reduce the cost and time while improving the performance of process [3].

TRIZ [4] or Theory of Inventive Problem Solving consider that technical systems will be developed in similar ways. In fact, it says that any problem can be connected to a general situation independent of original domain of the technical system. As a result, designer is able to extend the solution space into various domains of knowledge and apply problem-solving techniques from different fields of knowledge [5] [6] [7]. However, this theory supplies many ideas and has the following defects: it could not guarantee a solution and its feasibility, TRIZ provides only concepts and it could not directly propose implementable solutions [8].

INSA of Strasbourg has developed Inventive Design Methodology (IDM), which is an extension of TRIZ, in four main phases, from initial analysis to choice of solution [7] [9]. ID Methodology has not only inherited drawbacks of TRIZ but also has its own problems. For this reason, this methodology needs improving its performance because it takes time to give the best concepts. In addition, the ability of IDM to give the best result depends on the individual knowledge and experience of designer, and correctness of initial analysis. We propose to integrate IDM and LPD to solve these problems. In fact, this integrated framework can continuously help in removing wastes within the process; it can decrease lead-time of the phases. In summary, this combination has to improve performance of IDM's process and to increase its efficiency and agility.

This paper deals with Inventive Design Methodology and aims to propose the first integration of LPD in this methodology, with the goal of increasing its efficiency and agility. This paper is organized in four sections. In section 2, we present the state of art of Inventive Design Methodology, Lean, and its implementation in the sectors beyond manufacturing. The section 3 presents our proposition of integration of LPD in IDM. The paper finishes by the conclusion in section 4.

2 Literature review

2.1 Inventive Design Methodology

Nowadays, companies to survive in global market need to invest in systematic innovation, which is crucial for raising design effectiveness, increasing competitiveness and profitability [10]. Inventive Design Methodology (IDM) is a systematic approach, which has been developed within several years of research at INSA of Strasbourg to solve classical TRIZ limits, and to complete its body of knowledge with other theories such as graph theory or Pugh's theory [7] [9].

IDM is a framework, which consists of four main phases, figure 1, from initial situation analysis to the choice of solution concepts [7] [9] [11]. We briefly describe here these four phases, the employed tools or techniques in each step:

1. Initial Situation Analysis: This phase is to collect all the knowledge related to a problem and translate it into a graphical model in order to facilitate decision-making. In fact, this knowledge comes from a) patent, relevant literature, and company's internal documents b) existing data's regarding the targeted subject and c) tacit

know-how of experts concerned by the treated subject [9] [11] [12]. The applied tool in this step is problem graph. A problem graph is a set of problems, which are defined as a barrier that prevents the achievement of what has to be done, and a set of solutions, which represent an outcome that is known in the domain and verified by experience [13]. Nevertheless, in order to use TRIZ techniques to solve the problems and to gain solution concepts, it is necessary to translate the problems and the partial solutions to parameters. In this way, each problem can be derived in one or several evaluation parameters, and partial solutions into one or several action parameters. Then, these parameters will be applied to formulate the contradictions [13].

2. **Contradictions Formulation:** After completing the first phase, the initial situation analysis becomes visible as a reduced set of problems and partial solutions. It is used as departure point for formulating a range of poly-contradiction, from which the contradictions will be adapted [12] [13]. These contradictions are physical and technical issues, which represent bottlenecks in the development of system [9] [12]. The following sub-steps such as formulation of poly-contradictions, Extraction of contradictions, and classification of the significance of contradictions according to the specific of scenario are done within this phase [12]. The extracted contradictions become an input point for applying the different tools of TRIZ.
3. **Solution Concept Synthesis:** Once problems structured as contradictions, different TRIZ methods are applied to boost creation process, and to solve the precedence contradictions. These methods are the technical contradiction resolution matrix that relates to inventive principles, the substance-Field modeling related to the Inventive Standards system and the ARIZ-85C algorithm [12]. Contradiction Matrix is the most famous TRIZ tools. It is a matrix, which includes 39 improving parameters and 39 worsening parameters that are ordered on vertical and horizontal axis to interact with one another. This matrix is used to point out to the inventive principles that can be applied to eliminate the contradiction [14] [15]. Substance field analysis represents graphically the interaction, which there are between two components in a technical system, by a triangle model. Each triangle consists of one substance S1 that acts on substance S2 by a field, which is a kind of energy, acting on the instrument to adjust its interaction with the substance. A field can be thermal, chemical, magnetic, acoustic, electric, or electromagnetic. After developing the substance field models, Identification of system's problems is possible through further analysis. In order to solve revealed problems, TRIZ proposes 76 inventive standards, which helps us consider ideas from the world's knowledge bases [16] [17]. ARIZ or the algorithm for inventive problem solving is defined as a structured process that includes a series of steps integrating numerous TRIZ tools to formulate initial problems as well as resolve these problems [18]. It is known as the most appropriate for complex problems [15]. Since 1956, the different versions of ARIZ have been introduced. However, ARIZ-85-C, which is well improved compared to the other versions, and includes S-Field, operators, resources, etc., is the last version of ARIZ. This version of ARIZ contains nine steps including three steps to analyze and reformulate the original problem, the next three steps to eliminate the contradictions, and the final three steps to analyze the solution [19].

4. **Solution Concept Selection** : In this phase, measurement of the impact of each solution concept on the problem graph explained in the first phase will be done [9]. For this purpose, external experts should weigh the impact of each Solution Concept on Evaluation Parameter by filling out Pugh's like evaluation grid. In fact, if SC can make the EP develop in the desired direction, the assigned weight is positive, and if it could not make the evolvement in the favorable sense, the weight is negative [1].

Despite all the advantages that this four-phased framework to the designers presented, today, it does not have sufficient efficiency and agility to suggest the best solution. In fact, the identified areas of inefficiencies of each step of IDM are as the following: 1. Initial analysis: the essential time to collect and analyze the data, 2. Contradictions formulation: required time for this step, formulation of unnecessary contradictions, and inaccuracy in expressing the term, 3. Concept synthesis: time needed to understand the knowledge base, and errors in estimating the interest of new element of knowledge.

For improving the performance of ID methodology, we propose to integrate this framework with other methodologies or theory like Lean Product Development (LPD), which by continuously removing the wastes within ID process, can help to increase the efficiency and agility.

2.2 Lean philosophy

Lean philosophy was originated in the practices of Toyota Motor Corporation in the 1950s[1]. However, its introduction to the business world has been done through the books such as "Lean thinking" written by Womack and Jones in 1996, and "The Machine that Changed the World", which documents results of a study performed at the Massachusetts Institute of Technology (MIT), composed by Womack in 1990 [3]. Although, the concentration of these books was on the manufacturing aspect of business rather than engineering and design, the authors emphasized that the same principles can be implemented to remove all types of waste in various industrial sectors [3] [20].

Lean philosophy is based on the fundamental goals of the Toyota Production System (TPS) and can be understood as a set of practices, principles and techniques, which looks for removing continuously all types of waste in order to attain cost decrement, quality, efficiency and agility improvement with less endeavor [20] [21] [22]. According to lean, waste is defined as everything that does not directly add value to product or service [23]. In addition, this philosophy has recognized wastes in seven forms, figure 5, that have been classified as follows [24]:

- a. **Overproduction**: generating too soon and more than requirements, which causes a weak stream of information or products, and unneeded inventory.
- b. **Defects**: products or information that do not meet expectation because of problem quality, common mistakes in paperwork, and week delivery performance.
- c. **Excessive inventory**: unnecessary raw material stores, work in process (WIP), finished stock storage, and retardation of information or products, resulting in extreme cost and poor service.

- d. Unsuitable processing: unnecessary process steps, or processes that uses the wrong set of tools, procedures or systems, often when easier approach could have more effectiveness.
- e. Unnecessary transportation: any movement of products, information or people that is not an added value process step, and causes wasted time, effort and cost.
- f. Waiting: Idle time for information, people or products, which results long lead-time and weak flow.
- g. Excessive motion: poor structure of the work place, which causes extreme stretching and repeatedly missing items.

After introduction of Lean, there were the authors, which they have gone beyond the boundaries of manufacturing and adapted these wastes to other departments of business. Among these authors, it is possible to point out to (Ohno,1998; Liker,2004; Morgan, 2005; Reinertsen, 2009), which they have defined them in Product Development Process [25]. However, in order to remove waste and deliver improvement in specific area, it is fundamental understanding Lean Thinking principles.

“The Machine that changed the world” and “Lean Thinking” have articulated a universal Lean philosophy base on five key principles, which are essential to eliminate the seven wastes . Furthermore, these books have showed that how this concept by using these principles could be extended beyond manufacturing to any sector or department. The five principles and their brief description are as follows [24] [26]

- a. Specify value: define value precisely from perspective of customer in terms of specific product. Everything that absorbs resources but could not create value, it is kind of waste and should be eliminated.
- b. Identify value-stream: recognize all the activities required across the whole value stream to ensure that each of them provides value, and highlight non-value adding waste.
- c. Make value flow: make value-stream flow without discontinuity, waiting, deviation or scrap.
- d. Pull: provide or design what they are required on customer demand.
- e. Strive for perfection: continuous elimination of consecutive layers of waste when they are detected.

However, fulfillment of these principle needs application of some practices, which are activities applied to improve the organizations. These practices are implemented by set of tools and techniques [20].

Techniques and tools are essential to implementing Lean. In fact, application of these tools and techniques could be considered as a facility of defining, evaluating, and attacking sources of inefficiency in a specific manner [27] Some of the widely acknowledged Lean tools and techniques are as follows: a) Value Stream Mapping or VSM: to detect non-value-added activity, b) Cause-and-effect : to prioritize the root causes, c) DSM (Design Structure Matrix) : to understand the nature and root cause of waste, d) Single-piece flow : to employ the concept of single piece flow to remove waste time, e) A3 reports :to describe in one sheet the problem, solution alternatives, and the best commendation to solve the problem, f) Kaizen : to detect and eliminate waste according

to Plan-Do-Check-Act, g) Kanban: a visual signal to support flow, h) Quality Function Deployment (QFD) to identify critical customer attributes and to create a link between the attributes and design parameters) and Multi Criteria Decision Making : to weigh all the criteria against each other before making the final decision [25] [28] [29] [30] [31]. Integration of these tools and techniques are helpful for various of issues [27]. The principles of Lean philosophy have made it applicable to other sectors of industry, including innovation process, which plays today an important role in success of the business.

2.3 Implementation of Lean in the sectors beyond manufacturing

Today, most of the authors have written about application of Lean philosophy in manufacturing process. However, there have been the writers, which pay attention to integration of this philosophy in information management, innovation and product development process, because of its ability to increase efficiency and agility.

Within the information management, Hicks [32] propose application of Lean thinking to support the improvement of the performance of the overall information management, which is defined as the process of adding value to information by organizing, visualizing and representing, and enabling information to flow to the information customer.

In product introduction, which involves flows of information within the product development process rather than physical circulation of materials through the cases of manufacturing [2], Haque and James-Moore [26] describe the application of the five Lean Thinking principles to New Product Introduction (NPI) process. In fact, in their paper each principle is characterized within the context on NPI. In addition, they introduced the key methods and tools that enable Lean in NPI, and they discussed about the essential modifications to the manufacturing definitions of value and waste in order to incorporate to demands of effective and efficient NPI. In this field, Nepal [25] has proposed an integrated framework for increasing capability of identifying and eliminating of waste in Product Development Process by integrating LPD tools with DSM and Cause and Effect Matrix, which allows analysis of underlying complexity of PD, and facilitates specification of root causes of useless rework. In the same way, Anand et Kodali [3] have had a proposed conceptual framework for Lean New Product Development. The authors additionally integrated different tools and techniques to make NPD leaner. By looking at the presented examples of Lean applications to the sectors beyond manufacturing, and by considering this point that Inventive Design Methodology involves the flow of information, it can be concluded that the principles of Lean and also its tools and techniques, which needs some modifications, are applicable to ID methodology.

3 Application of Lean philosophy to Inventive Design Methodology

In this section, in order to apply Lean philosophy within Inventive Design Methodology process we propose five steps methodology, **Fig. 1**. The purpose of this applying, it is

to continuously remove the wastes in ID process and increase its efficiency and agility by applying different tools and techniques of Lean. In this methodology, the five steps, described below, explain how it is possible to constantly improve the process.

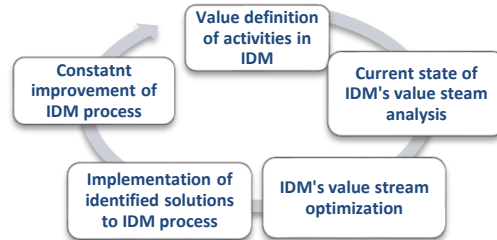


Fig. 1. The five steps methodology introduced to improve Inventive Design Methodology

1. Value definition of activities in IDM process: In this stage, the value of each activity should be defined according to the objective, which is convincing the designer.
2. Current state of IDM's value stream (process) analysis: This stage includes creation of value stream mapping of actual ID process, as well as wastes definition and analysis.
 - a. Value stream creation of the current process of IDM: in order to analyze the IDP, the activities within this process should be categorized as Non Value Added (NVA) activity, and Value Added activity(VA). For this purpose, it is possible to employ Value Stream Mapping (VSM), **Fig. 2**, which is a proven analytical tool for demonstrating flow of information in IDM process, and identifying different types of wastes.

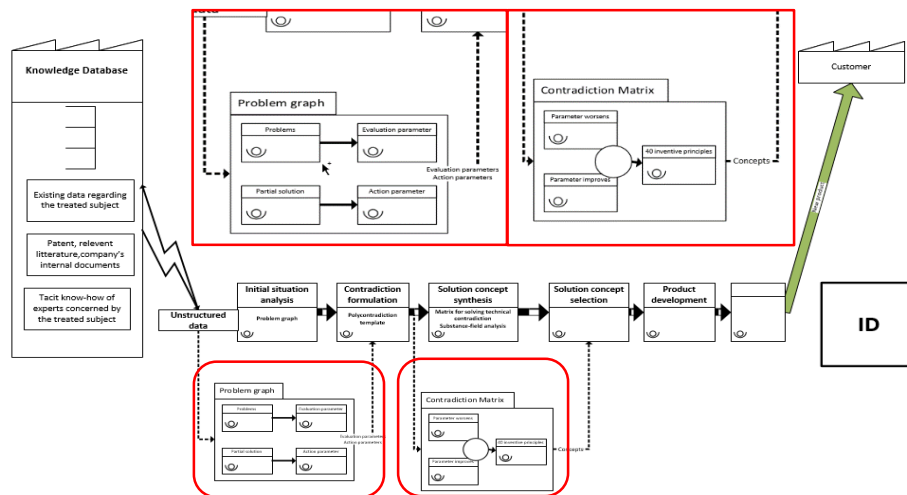


Fig. 2. Value Stream Mapping (VSM) of Inventive Design Methodology

- b. Wastes and problems identification of the actual process of IDM: After mapping the needed steps of IDM by VSM, it is necessary to identify different types of

wastes according to the adaptation that has been done in the second step, as well as the methods that should be changed.

- (1) In the Initial Analysis step, the user needs time to collect and analysis all the data as problems and partial solutions without paying attention to use of them in solution step. **Fig. 3** demonstrates a graph problem of a performed project, which has been done for this article to demonstrate IDM's drawbacks. As shown in this figure, the user has collected 22 problems and 5 partial solutions.
- (2) Contradictions formulation step: the users requires time to formulate all the contradictions that sometimes are useless. **Fig. 4** shows the formulated contradictions related to the graph problem of **Fig. 3**.

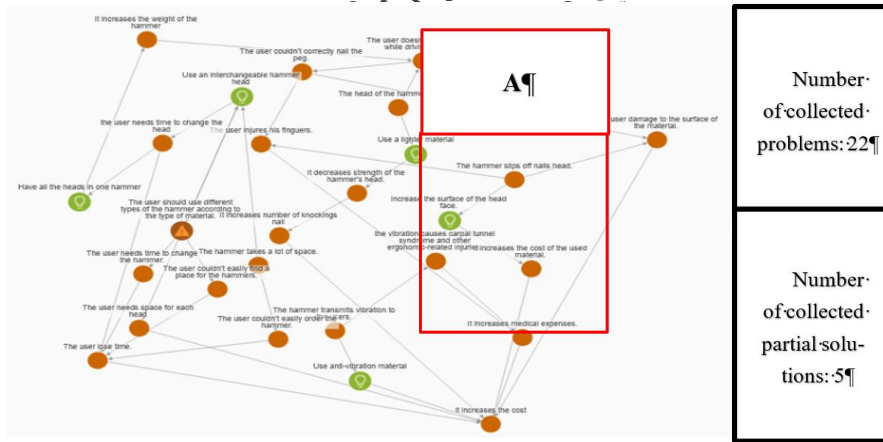


Fig. 3. Graph problem of a realized project (brown circles shows problems; green circles shows partial solution)

- (3) Solution Concept Synthesis step: the designer requires allocating a lot of time to understand the knowledge base. Furthermore, he could make errors in estimating the more interest of new knowledge element.
- (4) Solution Concept Selection step: of ID process, it is remarkable that after creating a network of a lot of problems and partial solutions in the first stage, and formulating all the possible contractions in the second stage, the designer applies just some of them to create the solution. For example, as shown in **Fig. 5**, in the presented project of step one, the designer has used just one of the contractions to formulate the solution. After verifying and comparing this project with other projects been realized by other designer, we received to the same results. **Fig. 6** demonstrates results of this review.

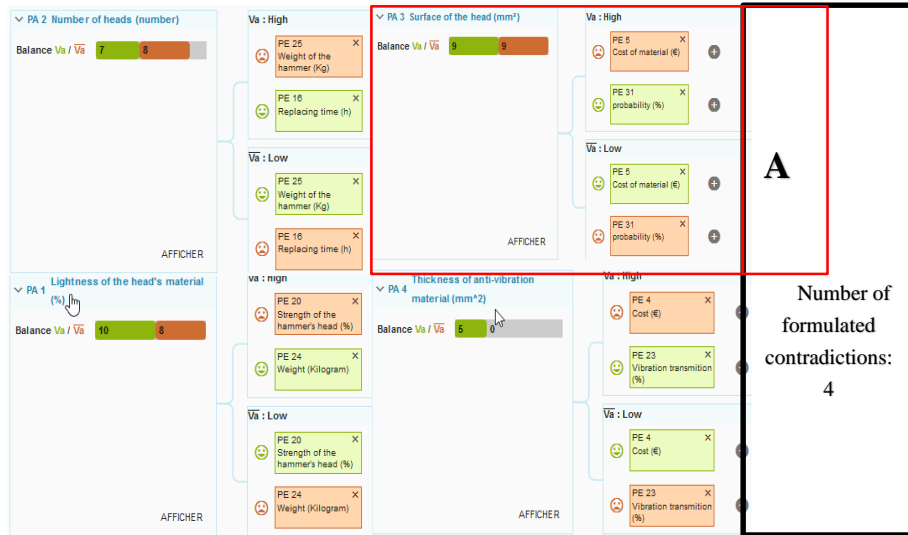


Fig. 4. Formulation of contradictions related to problem graph of figure 3

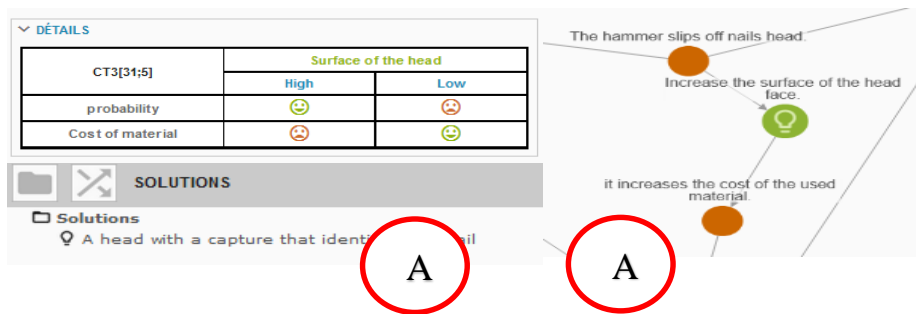


Fig. 5. The applied problem and contradiction to receive an innovative solution

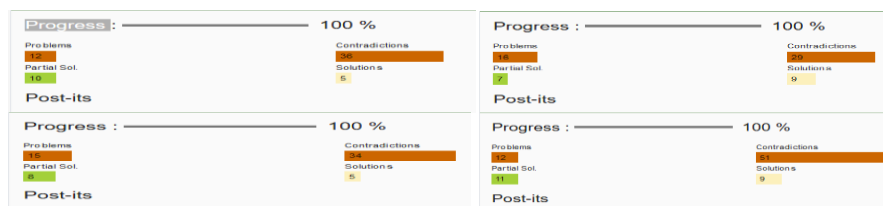


Fig. 6. The results of review of other projects

- c. Wastes analysis: This stage has been defined to find root causes of identified NVA activities in the previous steps and to prioritize them with respect to their impact on IDM process.
- (1) To understand the root causes of wastes: in Inventive Design Methodology process, it is possible to use the tools such as cause and effect chain or Why-Why analysis.

3. IDM's value stream (process) optimization: After understanding the root causes of wastes, it is the stage of identifying the possible solutions to remove wastes and propose the solutions to improve the process.
 - a. Identify the possible solutions to make the stream of information flow: suitable techniques or tools should be used to create flow of information. For example, it is possible to reduce the size of batch, apply the concept of single-piece from the initial phase of IDM to eliminate waiting time.
 - b. Identify the possible solutions to create a pull stream of information between downstream activity and upstream activity: the goal is to able the process to develop the information based on request of its immediate customer. In other words, each phase of IDM will produce information when is needed without break.
 - c. Estimate the future state of value stream of IDM according the identified solutions: After identifying all types of waste within IDM's process, the future VSM could be developed by predicting how Inventive Design process will be when the identified wastes are eliminated.
4. Implementation of the identified solutions to IDM process: the potential solutions could be implemented on Inventive Design Methodology in order to increase its efficiency and agility.
5. Constant improvement of IDM process: Continuous improvement is integral part of Lean philosophy. In fact, the goal here is to continuously improve IDM process by focusing on eliminating as many waste activities as possible while increasing the activities that generate value.

4 Conclusion

This paper dealt with innovation process and aimed to apply Lean, as philosophy to continuous eliminating wastes within the processes in order to achieve the excellence, in Inventive Design Methodology.

After a literature review about ID process in which a brief discussion on its main phases and applied tools in these phases was provided. An introduction to Lean philosophy and its application in the sectors beyond manufacturing was given. In the last, a five steps methodology, allowing to continuously identify wastes within ID process and to increase its efficiency and agility, was presented.

After applying the identified solutions, the new proposed algorithm and process, of the step 3 of the methodology into IDM process, we will have a flow of information from initial phase without waiting time. In addition, the information will be developed within the process base on the needs of the designer. The proposed methodology has to have also possibility to identify continuously wastes in ID process, and to propose the solutions to eliminate them. The final and the most important result of this five steps methodology, it is to constantly increase the efficiency and agility of Inventive Design Methodology.

In the future research work, we will present a new algorithm and a new process in order to increase the agility of Inventive Design methodology. Furthermore, the step 4

of methodology, which is implementation of the identified solutions to ID process, will be done.

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