Journal of Theoretical and Applied Information Technology
15th January 2020. Vol.98. No 01

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

LEAN DESIGN METHODOLOGY FOR LEAN PRODUCT USING UML MODELING

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ABSTRACT

The design phase is one of the crucial and important steps in the development of any product. All processes in the product life cycle are strongly determined by the product design, the concept of lean design aims to maximize customer value and minimize waste throughout the product life cycle by an optimized product design. However, and considering the complicated aspect of the design activity, a designer generating a holistic product design must take into consideration several parameters and aspects. Therefore, this paper argues for formalizing the product design methodology in a lean vision, throughout the modeling of different aspects of the product design process while integrate the lean principals, that can be exploited by company actors or software analysts. For this purpose, we used the UML modeling standard who has become an effective tool in information analysis in industrial design, we believe that such proactive collaboration between tools can significantly reduce the effort and time required for product design.

Keywords: *Lean design, Product design, UML modeling, Collaborative design.*

1. INTRODUCTION

In a recessionary context, many companies are clearly prioritizing cost reduction in order to optimize financial resources and try to limit the drop in operating margins. In order to achieve these objectives, the classic alternative is downsizing and non-strategic external spending. However, there may be another alternative: investing for the future to sustainably improve product competitiveness and conquer new markets. For this, new products need to be designed more quickly by controlling development and design, industrialization, production and operating costs for customers.

For these reasons, industrial enterprises have thought to set up the Lean Production System (LPS), the goal of such a system is to eliminate any kind of waste in the production process and align all processes on customer value, which has led to significant gains for these companies at different levels. The natural question was, whether or not, to use this approach for other manufacturing processes and to transfer knowledge acquired in lean manufacturing to other business processes such as product development or after-sales service [1].

At the design level of new products, optimized product design can generate significant cost reduction and quality improvement, the basic conditions for potential improvements are generally defined in the first stage of product life cycle which is the design stage, according to Ehrlenspiel 75% of product life cycle costs are already fixed by product design [2].

The design phase is the key step in development of any product, several researches focus on solving conceptual technical problems related to design activity[3,4,5,6,7], others focuses on the organizational aspect taking into account human factor and design profiles participating in the development of processes and products[8,9,10].

All the teams involved in the design activity must be able to communicate with each other and share information over extended distances. For rapid product development, accurate information must easily be accessed. This article focuses on product design decision-making, by all teams and especially those from the design team, which is in some ways the focal point of the flow of information.

The use of modeling tools has therefore become a crucial factor, and a key resource within a company. It has already been shown that product design tools and the use of information technology (IT) are interlinked within the activities of product design. However, the use of such facilities and tools by the

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

engineering design team is not frequent as one may expect.

With the intention of standardize these processes and capitalize the knowledge around the different profiles (business, software) to be able to work with them, several modeling standards have been implemented, among which we propose UML [11, 12], which is used today as a new analytic procedure in the industrial design [13], and modeling software projects and business processes.

The proposed methodology have to support designers in both individual learning and collaborative work as well as enhance communication between company departments, using this methodology gives an opportunity to define a common language, structure and make goals visible to different actors.

2. BACKGROUNG AND GENERAL CONCEPT

This section presents the basic concept concerning Lean Manufacturing, Lean design and the Unified Modeling language (UML), to better illustrate the context of the terminology.

2.1 Lean manufacturing

The concept of lean manufacturing have achieved high popularity in recent year, The 'lean' concept evolved from the shop floors of Japanese manufacturer, Toyota Motor Corporation, which focused on the reduction of waste in operations [14, 15]. The concept of lean manufacturing became popular through Womack, Jones, and Ross (1990) in their book "The machine that changed the world", Lean thinking is a business approach that delivers better value for customers by removing non-value-adding activities [16]. In the Lean context, waste is defined as "anything other than the minimum amount of equipment, materials, parts, space and time which are absolutely essential to add value to a product" [17]; Lean approach identifies seven forms of waste: overproduction, transport, motion, waiting, inventory, overprocessing, and defects. All of these wastes have a direct impact on performance, quality and cost, and these are all non-value-adding operations for which customers do not want to pay [18].

The Lean approach is defined according to five principles [19]:

• Define value: The Lean approach begins with a detailed and accurate understanding of the value the customer places on products and services. This determines what the customer will pay.

• Identify value stream: The value stream is the totality of the product's (or product family's) entire life-cycle from the raw materials through to the customer's use.

• Make value flow: the flow of the remaining steps must run smoothly without interruptions or delays.

• Let the customer pull value: produce goods or services only if the client has explicitly requested them.

• Pursue perfection: The manufacturer strives to achieve nothing short of perfection. The march toward perfect process happens gradually as continuous improvements address root causes of quality problems and production waste.

2.2 Lean design

Lean design is a term increasingly being used by both academics and practitioners to refer to lean principles applied in the context of design [20]. The concept was developed from the basic idea of Lean Thinking, the specific idea of this approach is to focus on value-added activities from the point of view of the end customer. Therefore all activities with non-value-added must be eliminated or at least reduced during the product life cycle, these activities which do not contribute to the value of the customer are called waste [21]. Lean Design aims for the same goal, but follows a different approach. Indeed, according to this approach, it is not the processes within the product life cycle that must be optimized, but rather the design itself. This approach is based on the fact that 70% to 80% % of the customer value and waste that occur downstream of the product lifecycle process depends primarily on decisions made during the design phase [22]. From the perspective of the consumer of the product or service, the value refers to the expected functionalities of the product or process, and what the customer is willing to pay for [20].

According to Dombrowski [23] three different definitions of a product can be derived depending on the difference between product design, value, and waste.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

• From a design point of view: the product is the sum of the parts, its properties and its relations.
• From a value perspective: the product is the sum of all functions it delivers or properties it offers to create customer value.
• From a waste perspective: the product is the sum of all the life cycle processes.

Lean Design provides an integrated model, methods and qualitative guidelines for product design to increase maximum value for the customer and minimize waste [24]. These guidelines help designers by providing recommendations for making good decisions during the product design phase. These qualitative design guidelines are suggestive in nature and focus primarily on the prevention of wastes during the early stages of the product life cycle, however, the applicability of these design guidelines must always be questioned in the context of conditions of the company [23]. Qualitative design guidelines provide general design recommendations, however the transformation of these guidelines into the actual design remains difficult due to their low level of detail especially in advanced product development phases where more specific guidelines become necessary [25]. Table 1 illustrates some qualitative guidelines for product design from the point of view of both authors Huthwaite [24] and Mascitelli [26].

Table 1: Some design guidelines according to lean design literature.

qualitative guidelines from Lean Design		
Product features	***Huthwaite***	***Mascitelli***
Minimize the number of parts	*	
Minimize the needs for special tools	*	*
Avoid complexity	*	
Simplify assembly	*	
Reduce the danger when using product	*	
design scalable requirements		*
Use standard components	*	*
…….		

Morgan [27] identified eleven wastes related to product development:
• The transfer of products or processes from a service to another;
• Unnecessary data collection;
• Expectations: of data, answers, decisions, revisions, availability of a resource;
• Time and effort for the work organization to be done (negotiation of contracts, meetings on quotes, calls for tenders and selection of suppliers ...);
• Reinventions: processes, solutions, methods and already existing products;
• An unstructured system: poor roles and responsibilities included, low responsibility, lack of planning and incompetence;
• Strong variations in the process;
• An overused system, or too fast;
• Ineffective communication;
• Large lot sizes (represented by the number projects in progress);
• The non-synchronization of processes in progress.

2.3 Unified Modeling Language (UML).

Unified Modeling Language UML, is a visual tool and graphic language for modeling, specification design and documentation of object oriented systems [28,29,30]. UML became increasingly the design standard for software engineering and development area, throughout the last decade this language is used for modeling, analyzing, projecting and implementing the software system. Based on the object-orientated modeling all process could be presented by using cases models as rough specification and by structural diagrams and behavioral diagrams as detail specification [31].

Created and standardized by the Object Management Group, UML is a general-purpose software modeling language that provides a standard way to visualize the design of complex software systems; it can also be used for non-software development and information system design. Indeed, UML can be used in the collection of process requirements, and is considered a major tool in the business process management [32] as used during the process definition and analysis phase [30, 32].

The main characteristics of UML is that it is a methodology independent modeling standard: whatever the design and analysis processes. In this paper, we chose UML 2.0, According to OMG, UML 2.0 defines thirteen types of diagrams focused on three major categories:

Structure diagrams: represent the static aspect of the system. These static aspects represent those parts of a diagram, which forms the main structure and are therefore stable.

Behavior diagrams: describing the dynamic aspect of a system. Dynamic aspect can be further described as the changing/moving parts of a system.

Interaction diagrams: representing interactions among the components of the system.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

We will focus in the next section on behavior aspect of our design phase: described in the use case diagram as well as the activity diagram, and on the structural or static aspect described in class diagram.

3. MODELING OF LEAN DESIGN PRODUCT'S

In this section, we propose a modeling for the lean design product methodology. We opted for the UML format language modeling standards, in the objective of describe all aspects of the design methodology and obtain understandable and standard models that can be easily interpreted and reused.

In the case of this study, we consider the design of a multi trade product (requiring the collaboration and cooperation of many disciplines example: product that contains multiple components mechanical, electronic and software), which is composed of several articles, each article is composed of several interfaces.

3.1 Modeling product design with lean design approach

The influence of the design phase on the results of design projects, both technically and economically, is extremely important. It is precisely in this phase that the client's ideas and speculations are conceptualized in a physical model, defining his needs and requirements in procedures, drawings and technical specifications. However, the administration and product design engineering have hardly been explored and illustrated. Research findings show how the integration of design within product development can positively affect the financial performance of a company as well as its corporate identity and brand [33].

According to B.Hutwaite [22], from the perspective of lean design, a product is created to deliver high value with low waste. Indeed, the integration of lean design into the product design can bring several benefits for companies. In our proposal methodology, the existence of a lean design entity is crucial as it helps achieving a better results in terms of definition and requirements of the market's needs, define design specification, define design guidelines for the product, identify and eliminate/reduce waste during the overall project.

In this context, the lean design team may be useful in seeking, among other things, to eliminate non-value-added activities. It is possible to eliminate non-value-added activities such as loose meetings where all actors are not concerned (waste: time and resources), work done in duplicate when for example the "designer" must take over the drawing and the remake on computer (waste: time, resources and expertise). To achieve this, the Value Stream Mapping (VSM) modeling technique can be adapted to product development and the creation phase in order to highlight, what brings or not, the value according to the client's final voice. The types of waste can be adapted to the development process. For example, the overproduction would be the production of drawings or models larger than necessary or with a level of unnecessary detail. Unnecessary processes would involve superfluous serial efforts, too many iteration loops, unnecessary data conversions (2D drawings to remake in 3D), excessive checks, and changes in marketing ideas. The wait can also be translated into too long process of decision-making and document signing, delayed access to documents or products generated by dispersed teams (head office and factory). The elimination of waste would certainly favor the establishment of a more precise schedule allowing a forecast of loads and a smooth of production in terms of design of products. Among the other lean practices, the use of visual indicator management could be done through a dashboard indicating the progress of ongoing projects.

The lean design entity has to define Value for the Customer by:

- Providing the information to understand customer needs and what customers value (what the customer is ready to pay for).
- Transforming customer needs into product specifications and plans oriented to maximizing the customer value proposition.
- Minimizing waste (high cost and poor quality) and maximize value in the design of the product.
- Developing more optimal solutions to maximize customer value, increase product value.
- Avoiding unnecessary, process steps, and procedures, and use value stream mapping to eliminate waste.
- Establishing a common way of doing things – standard document templates, process, checklists, and design documents.
- Reducing development time and cost.
- Improving product profitability.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

- Coordinating with the different departments involved in the project to maintain the desired level of product design.

In this paper, we consider the design phase in its general aspect: which concerns all process related to the specification of the need, feasibility study, preliminary and detailed design, prototype realization and test, integration and validation steps. The product life cycle contains other related steps, such as, production, marketing and sales and other market or product related steps. Figure 1 shows an example of a product design process steps with the different phases and its different inputs and output documents.

3.2 Modeling the behavior aspect with use case diagram

The use case diagrams describe aspects of software systems' behavior, it demonstrate the different ways that a user might interact with a system or in our case, the process being modeled, focusing on the roles assigned to its participants called "actors" and their respective functions known use cases [28,29,30].

Figure 2 shows the use case diagram corresponding to our lean product's design methodology. The diagram shows the functionality of a system using actors and use cases. Use cases are a set of actions, services, and functions that the system needs to perform, we can regroup all our main actors in these main categories:

- The direction entity: responsible for defining design guidelines and strategies about the project.
- Lean design entity: responsible for identifying the appropriate Lean deliverables and activities to include in product development to support the company's Lean strategy. This entity defines appropriate lean design guidelines for the product, maximize value for the client, and minimize waste during the whole process of product development. It also plays a crucial role in the success of the entire project, this entity collaborates with the different actors such as Product marketing entity, Production entity, Project development entity in order to optimize the product design.
- Product marketing entity: responsible for proposing new products, for which it expresses the need for market, define the needs and expectations of the client and translate them into commercial characteristics, benefits and uses, and get an idea about the competitors. Also, this entity focuses on product changes when needed in collaboration with the project manager and Lean design entity.
- Production entity: Responsible for the mass production of the final product, also collaborate during the prototype manufacturing
- Project development entity: coordinates the internal product development process by ensuring that the project is on schedule and on budget. The project leader tracks progress and coordinates all internal resources and team members (engineers and designers) to deliver the product on time.
- Project committee entity: validate deliverables using predefined decision criteria, it approve the specifications of each article and its interfaces.
- Stakeholders (clients, investors, even users of a product): These are all people involved in decision-making and interested in the final product (Provide feedback on product ideas, describe the requirements in details, and contribute new features to the product development…), who can influence the process of product management and development.
- The product development entity: Responsible for the various phases of design and the elaboration of an article, since the definition of its specifications and its interfaces up to the article making in collaboration with production, as well as product testing and validation under the supervision of the project Committee.

The interactions between the different entities, the rules of each actor involved in the design phase are described in detail in the use case diagram figure 2.

3.3 Modeling the behavioral aspect with the activity diagram

The activity diagram describes the dynamic aspects of the system by presenting their flow at system level as well as at business level by describing the actions' succession of a system [28,29,30]. The activity can be described as an operation of the system, the control flow is drawn from one operation to another.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure 3 shows the activity diagram of our lean design methodology for product design, The diagram clearly indicates that the design process starts with the market study and its needs to be led by the product marketing entity, and ends with mass production of the final product. Between these two activities we find a panoply of activities that make up the process of designing a new product as defined above in the use case diagram (figure 2). The rules governing the succession of activities are indicated if necessary. For example, we cannot proceed to define product specification stage unless the product development project proposal is validated and approved by direction entity.

The different input/output documents for each activity are also represented on the graph. As an input to the definition step of the product specifications, we find the specifications and product definition document produced by the Product marketing entity, product development entity and lean design entity, and as an output, we find the detailed product specification document.

3.4 Modeling of the static structure with the class diagram

The class diagram describes the structure of a system by showing the system's classes, their attributes, operations (or methods), and the relationships among objects. It also outlines the relationships between entities ranging from composition, inheritance or simple associations [28,29,30].

Figure 4 describe the class diagram that corresponds to our design process, it shows the fundamental constructions and interactions of a system such as inheritance, aggregation, and association. The diagram shows us for example that lean design entity may be involved in several product development project at a time, therefore, each lean design team can only be in charge of a single product development project at a time.

The product is composed of many items or articles and each article itself is composed of several interfaces. Each product with its articles and interfaces has a set of specification, test, validation and design documents.

4. CONCLUSION AND FUTURE RESEARCH

Organizations across the globe are under immense pressure from customers, and stakeholders to manage their processes in a responsible manner to improve their product's design, thus, finding a way to improve design product has been a challenging task for many companies that aimed to meet the expectations of their customers.

Lean Design states that the effects of product design have a great importance on customer value and product lifecycle processes, the design methodology modeled in this article is the standardization of the product design in a lean vision, it promotes the maximization of customer value and the minimization of waste for an optimized design process. UML modeling can provide a graphical view of all the required information of a project, in turn, accelerates the design process so that quality is preserved and design is optimized, in addition, since UML graphics can show the design procedure from different points of view, it can be used by different entities and groups.

Today, information technology (IT) has become the driving force in delivering improvement in product design, information flow, and data transfer between design teams and external parties, as well as assisting design teams in the efficient execution of their work.

The application of lean design methodology using UML modeling should be gradual, companies should first assess their weaknesses and strengths in order to set up improvement paths, set priorities and identify objectives for implementation. This paper is one of the very first researches that integrate lean design approach with UML modeling, and therefore offers the potential to be applied in product design activity to help the design teams to design lean products.

In this article we propose a product design methodology based on lean design using UML modeling, in the future, the proposed methodology could be applied to other industrial sectors and manufacturing firms where it is essential to improve the design process in a lean vision. The model can also be modified to integrate other more advanced lean design tools such as Axiomatic Design (AD) [35].

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ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

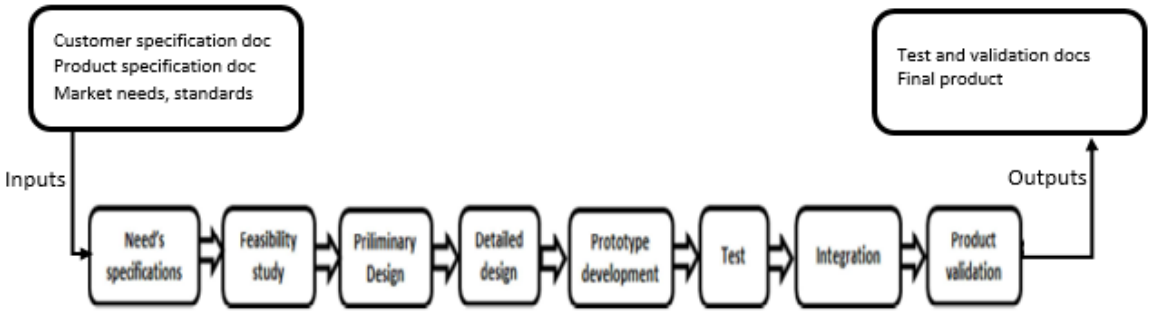

Figure 1: Example of product design process

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

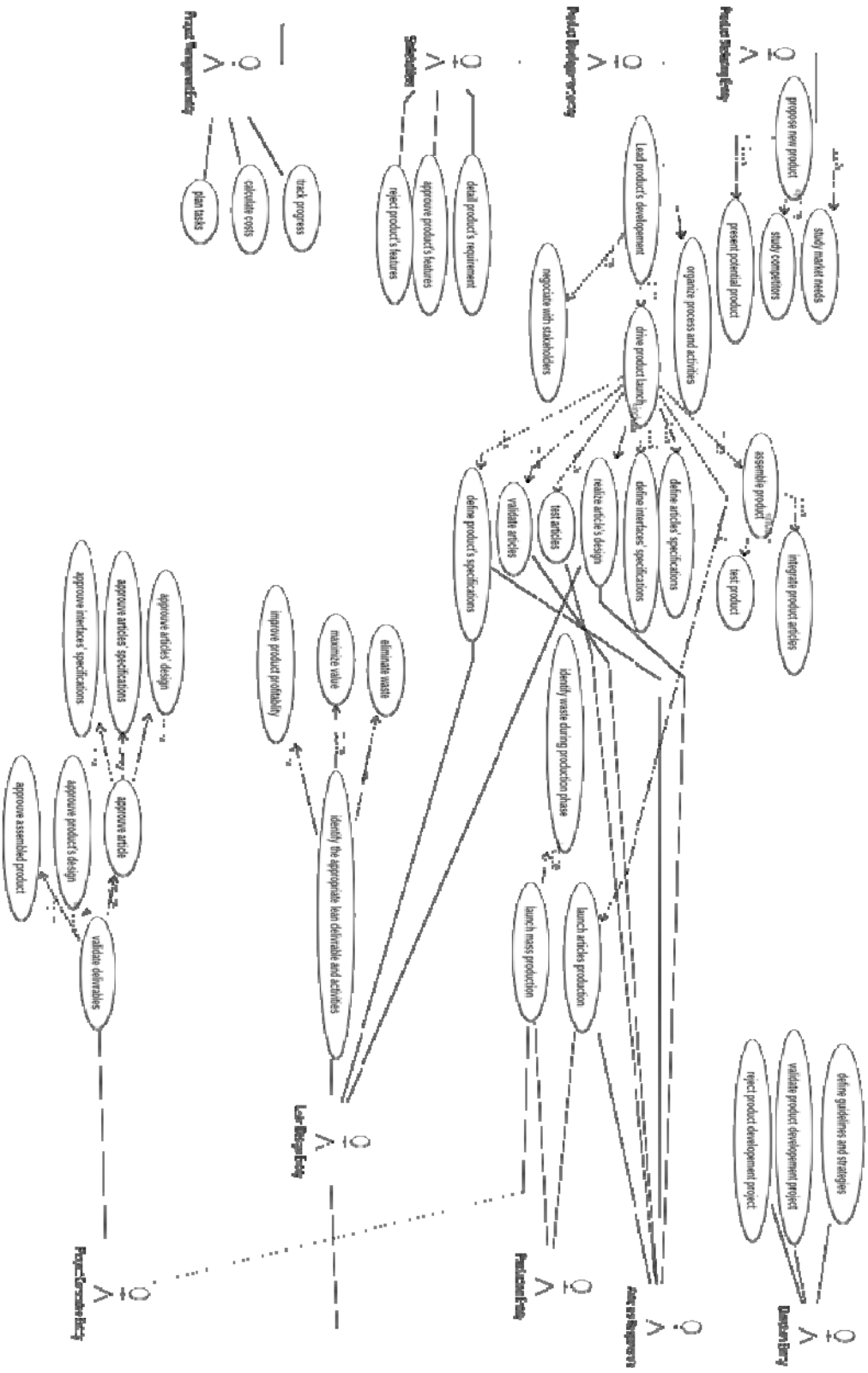

Figure 2:The UML Model of Lean design products (Use Case Diagram)

Journal of Theoretical and Applied Information Technology
15th January 2020. Vol.98. No 01

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

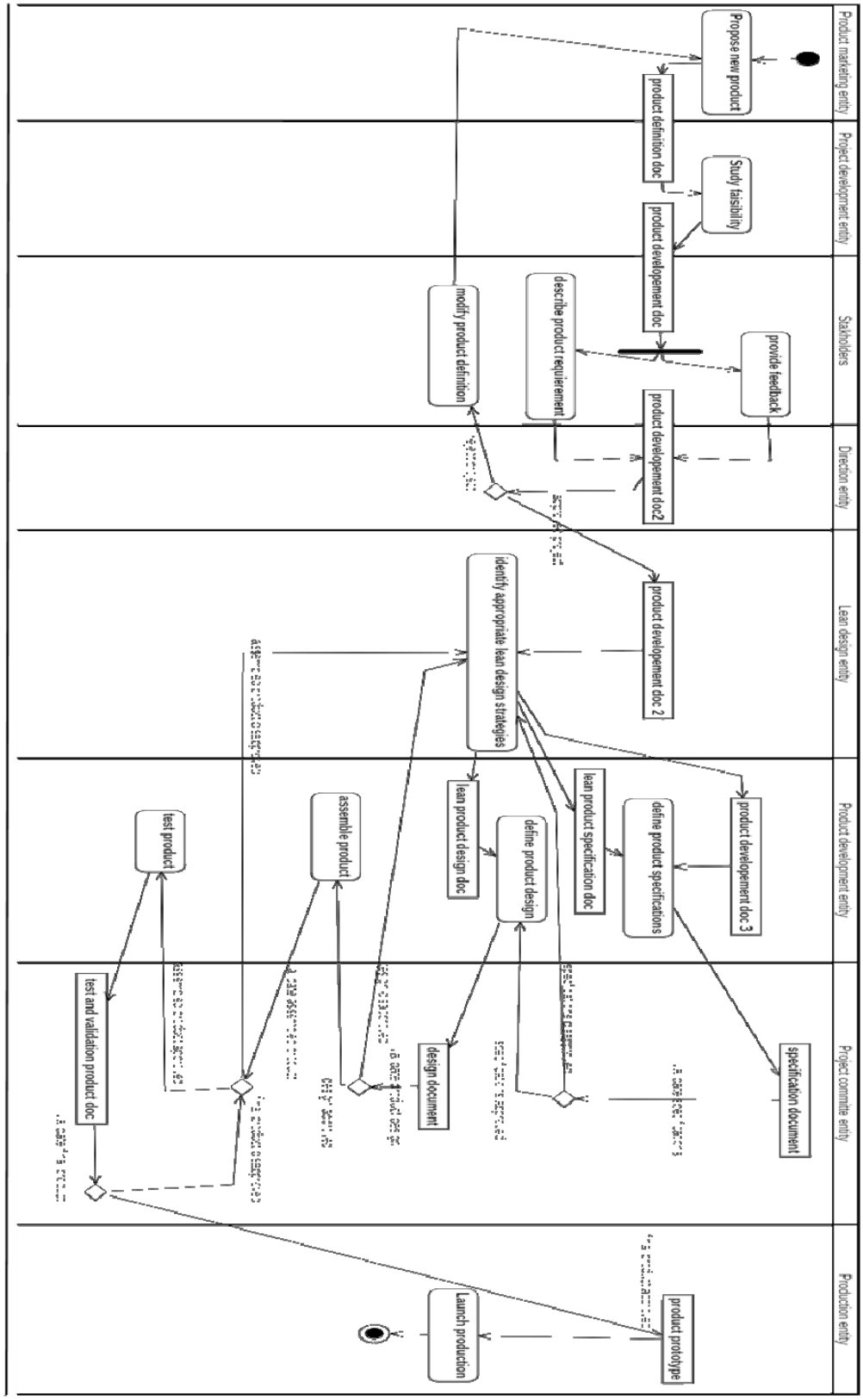

Figure 3: The UML Model of Lean design products (activity diagram)

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

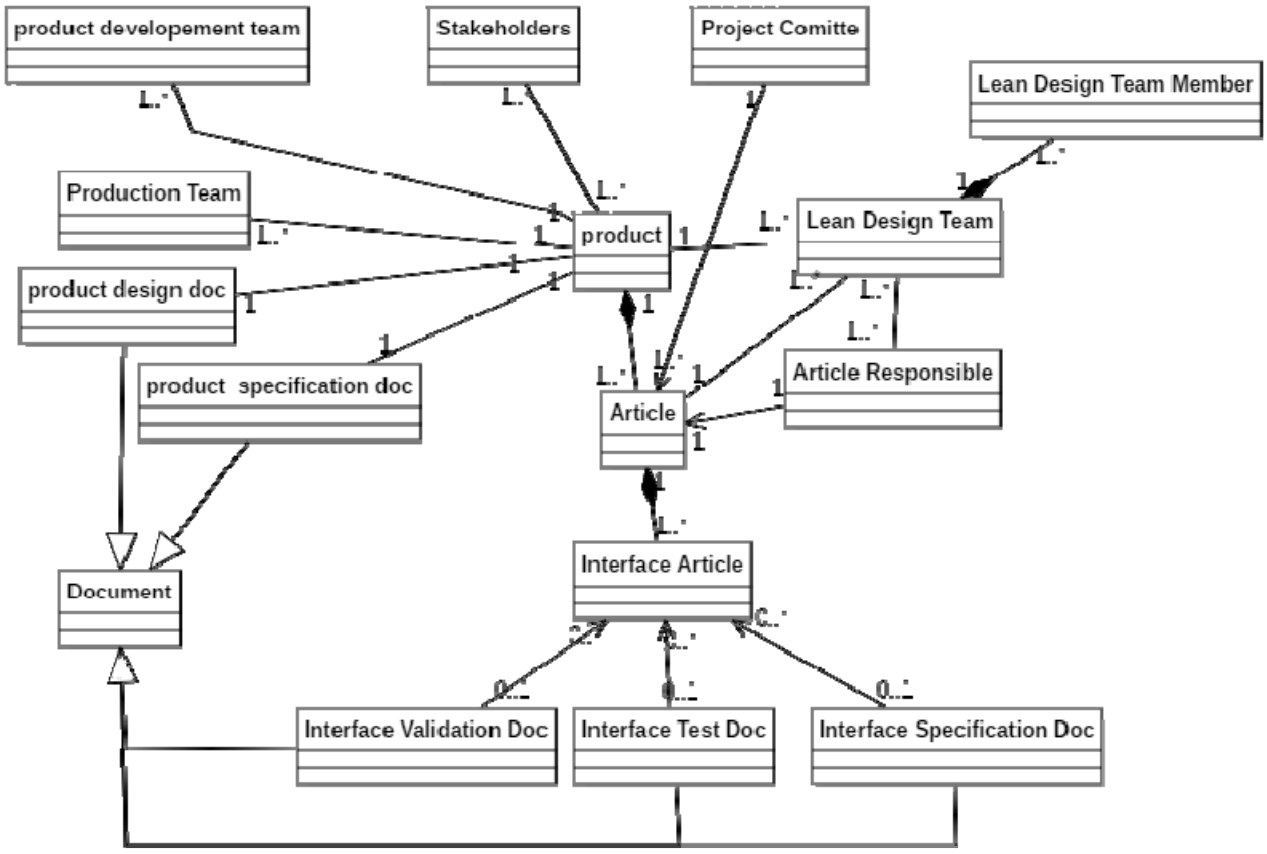

Figure 4:The UML Model of Lean design products (Class diagram)