# DEVELOPING A MEASUREMENT MATRIX FOR LEAN PRODUCT DESIGN

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# Abstract

Today, many companies are familiar with the concepts of lean enterprise management and have applied the lean philosophy to their product design process. To study the impact of such practices, measurements need to be developed to evaluate the leanness of a company's product design. Overwhelming amount of literature on lean management and its application to new product development exist. However, most of them focus on the overall strategies and no consensus definition of lean product design exists, not to mention a measurement matrix for lean product design practices. In this thesis, a lean product design measurement matrix is developed based on a comprehensive review of literature in lean product designs. Factors that can be used to assess a company's lean product design practices are identified. The lean product design matrix developed in this study will help companies to measure and evaluate their lean product design process and therefore, focus on key elements needing improvement. It will also facilitate researches that study the impact of lean product design practices on a company's performance overall and in specific areas.

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CHAPTER 1

# INTRODUCTION

Throughout the history and in today's world, successful stories about the implementation of lean management have led to the popularity of the lean enterprise management and its application in many areas beyond the manufacturing where it was originated. The first entrepreneur in the industrial world who practically applied the "lean" mindset was Henry Ford [1]. He used lean practices to eliminate the waste from the automobile manufacturing and assembly line. The result was a great increase in efficiency of production in terms of reducing the production time and cost while maintaining the quality. Ford's success in implementing lean principles inspired other businesses to follow his strategy to improve their production performance[2].

Toyota company developed its own lean framework called Toyota Production System (TPS) after observing U.S. automotive industry and learning from Ford company[3]. In Toyota Production System, the lean concepts previously applied by Ford were more classified. For instance, wastes were categorized into seven different classes that facilitate the process of identifying and eliminating them[4]. In addition, in TPS the value of the system was clearly defined as delivering customers' requirements. Toyota became one of the most successful and growing companies as a result of its lean strategies. Toyota Production System's success made a revolution in manufacturing lines which motivated the competitors in automobile industry and even other industries to learn and implement TPS strategies to their benefit.

There are several companies in the current market that have applied lean practices into their design process which enabled them to make a huge improvement in their business and helped them to become a leading company in their field. For instance, Spanish apparel retailer ZARA used lean production strategies to apply new designs into its stores in 14 days while keeping the costs low. As a result, by applying lean practices, it is closing to the title of world's biggest clothing retailer that almost quadrupled its sales, profits, and locations since 2000 [5]. Another example is Lista International Corporation. The main purpose of implementing lean practices at Lista International Corporation was to provide customers a broad offering of high quality custom storage products in the shortest possible time. Lista has decreased its inventory by 35% and eliminated the need for a 17,000 square feet finished goods inventory warehouse after implementing lean thinking strategies in its procedure [5].

In the tourism industry, Marriott Corporation was one of the first companies that decided to apply lean design strategies into its system. As a result, the service score for Marriott Towne Place Suites was increased by 10 points to 87 which resulted in its ranking to be in the top 10% of its competitors. The improvement positively impacted the hotel's performance through revisiting customers [5].

Today, many companies are familiar with the concepts of lean enterprise management and have applied the lean philosophy to manage the various endeavors they may have. One of the areas where the lean management philosophy and practices can be applied to improve a company's overall success is the product design phase. An overwhelming amount of literature on lean management and its application on new product development exists. The lean design related articles usually present an overall

definition of lean as increasing the value adding activities and eliminating the wastes, and then focus the discussion on a certain piece of product design process such as customer information. While adding customer value and removing wastes from the design process are two essential elements that construct the soul of lean management, other specific factors that are required to make a process lean should be also identified and summarized in a systematic way. Without a consensus definition on "lean product design" process and a list of critical factors, it is hard for an organization to prioritize its product design activities for being lean. For companies that are practicing lean design for years with or without recognizing it, a measurement matrix can be very helpful to evaluate their product design process. As it is widely acknowledged, especially in the lean environment, continuous improvement built on benchmarking is critical to the organization's success. Without a measurement matrix, it is impossible for a company to assess, benchmark, and continuously improve its lean design practices.

In this study, through extensive literature review, I try to develop a measurement matrix for new product design that enables organizations to evaluate themselves in terms of being lean. These measurement factors enable companies to convert the qualitative concept of lean product design into a more sensible and quantitative concept.

This thesis is organized into five chapters. The topics of each chapter are as follows:

In *Chapter 2*, the different stages of traditional new product development and lean new product development are discussed.

In *Chapter 3*, the research question, research method, and the main purpose of this study are explained.

In *Chapter 4*, the developed lean product design measurement matrix is presented.

*Chapter 5* includes the concluding remarks, limitations and future work of this thesis.

CHAPTER 2

# LITERATURE REVIEW

## 2.1 New Product Development

New product development (NPD) can be defined as offering a product with new attributes that will provide new or additional benefits for the final users. Product development might include improving an existing product or creation of entirely new product from ground zero. New product development might seem simple in definition but it is a creative and interdisciplinary activity that is essential for economic success of organizations [6, 7]. Companies that do not pay much attention to development or cannot complete their product development process properly will lose their market share to their competitors [6]. The different stages of new product development are summarized in Figure 1 and discussed in details in the following section.

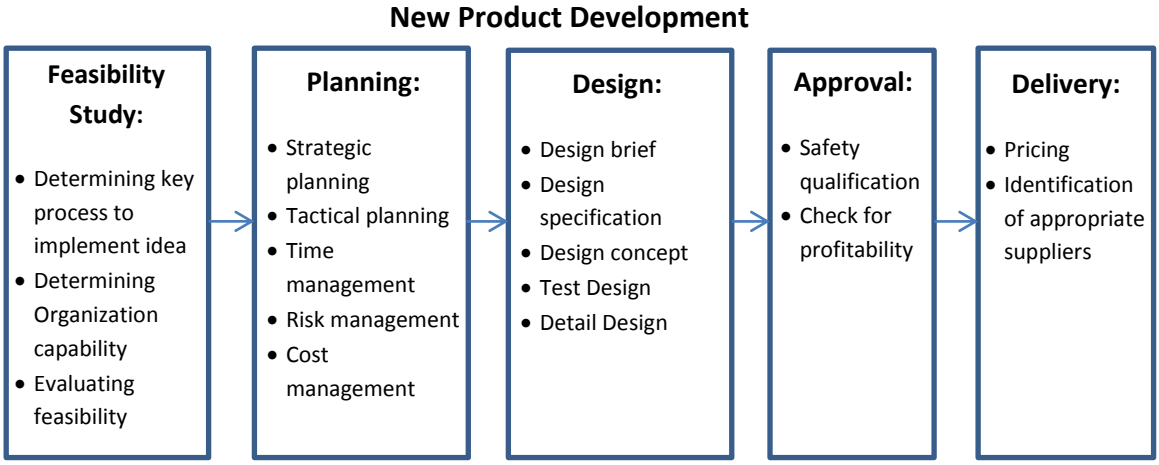


Figure 1 New Product Development Stages

### 2.1.1 Feasibility Study

In feasibility study, an analysis is performed to investigate the viability of an idea [8]. Determining important steps in product development process and assessing their

relationships with organization capability is vital. There might be enormous innovative ideas that can be implemented to a product to improve its performance, but it is essential to evaluate an organization's capability and then refine the ideas that are possible to be accomplished within the organization's capabilities [8]. Although it is acceptable to consider ideal concepts as a long term goal for a certain product design, having short-term realistic goals is necessary.

The first step is to define a feasible business idea. Any idea that is capable to generate adequate amount of profit and cash flow, remain viable for a reasonable period of time, and resist the probable risks it might encounter can be considered as a feasible business idea [8]. In feasibility study, experts try to define and evaluate required resources including time, budget, and human resources for the development and compare them with the capability of the company. They also need to perform a market assessment to realize how profitable their final product can be [8]. Identification of other competitors and their economic condition will help organizations to determine the amount of cash-flow and start-up investment they need to start with. It also will be useful to recognize the fraction of market share that will be available for the new product. Moreover, SWOT analysis is a useful technique which enables organizations to identify their strengths and weaknesses in a way that help them to embrace more opportunities and manage the threats that they may encounter. Although SWOT analysis is not a part of feasibility study, identification of weaknesses, strengths, threats, and opportunities can be very useful to come up with more accurate decision. In a nutshell, at the end of the feasibility study, the organization should be able to answer the question that if the final developed product will create viable business venture or not.

### 2.1.2 Planning

Although future is unknown and any information about future is related to uncertainty and risk, appropriate planning will help organizations to decrease the probability of failure. At the first step, it is necessary to outline a big picture of the product and ensure that all the development team members understand the defined vision[9]. After identification of the current situation and the goal, the required tasks, process, and resources need to be defined [10]. In other words, organizations should define a long-term strategy that facilitates the new product development cycle. Then, it is necessary to define short-term achievement. These short-term goals will act as checkpoints and help organizations to track their progress. Besides the strategic planning that directs organizations to the final goal and helps them to identify any deviation from main mission, organizations need to have a tactical plan that helps to recognize how organization's resources should be used in each sub-process to achieve the goal [10]. Organizations should be open to any change in planning. Some changes are inevitable, but should be minimized to avoid reworking. It should be remembered that the goal is to develop a product successfully and not to prove the validity of the plan[10].

One of the important activities in planning is time management. The competition in the market forces organizations to launch new generations of their products periodically. In some cases, the products may have a short life-span while the product development is not fast enough to cope with it and cause problems for the company. The companies in this case may lose the market share they have to competitors[9-11]. Consequently, shrinking the development time as much as possible is crucial. The required time for accomplishment of each task should be allocated. In addition, the

relationships of the tasks need to be identified: Some tasks can be done in parallel while some others need to be done in a sequential manner[11].

Usually, the money that is spent on a development process and the time it needs to complete it are reversely related. Reducing and controlling the costs may cause companies to finish the process after the due date, which means delay in delivering the product. Time overrun will significantly increase the payback period time and it will reduce the economic performance of the company[10]. Consequently, time overdue is much more important than budget overrun. For instance, in a specific case, controlling the costs helped the company to save about 3 percent of the total investment; however it made the payback time 2 times greater than what it originally was supposed to be [10]. Also, for each day of delay in the development process, organizations should pay for their resources, so being on the schedule should be considered when trying to control the costs[11].

Risk management is one other step of planning. The product development team need to create a risk profile for each tasks. In this profile, the identified probable risks and uncertainties relating to each task are provided. Also, appropriate alternative solutions for each of the cases are determined that will facilitate the process of managing the risks and uncertainties [10].

### 2.1.3 Design

In this stage design teams will review and refine the ideas that they have listed. This refinement process is based on the results of feasibility study for each of the ideas. Then, they will try to specify the appropriate methods to accomplish the selected features. They will integrate different features to see the final result and also be able to test the

whole concept to see if it satisfies the required conditions or not[12]. The design stage includes different steps that are described in the following sections.

#### 2.1.3.1 Design Brief

"Design brief" is a written document that will be prepared by design team members. They will explain the needs for the design as a well as the desired result that they expect. In this step, designers will describe the whole concept of product that they are going to design [13]. It can be the same as the vision they defined in the planning stage. The users of the products or services will also be introduced in the design brief document and the target customer will be identified [13]. A clear target customer is really essential since if the organization does not have any customer focus, it means the product will be created to satisfy all different types of customers which is impossible. People have different expectations and an individual product cannot satisfy all those needs. Also, in design brief they will explain that if their final product is an entirely new product or an improved version of an existing product [10].

#### 2.1.3.2 Design Specification

In this step, designers will describe the features that they are going to add to the product, and also methods they are going to use to implement those features[14]. It is important to help the entire team to understand features and methods to prevent from any misunderstanding and confusion during the design process. Based on their recognition about customers' requirements, the approximate amount of profit that each specification can generate, the unity of features among competitors, necessity, and the time required to be spent to implement each feature, the design team will rank the specifications and they will try to accomplish the development process by implementing as much as they

can[12]. A design specification must include all necessary drawings, dimensions, environmental factors, ergonomic factors, aesthetic factors, costs, required maintenance, quality, safety, documentation and description[12].

#### 2.1.3.3 Concept Design

Concept design is one of the most complex steps in new product development process. As mentioned, in the design specification step, design team ranks the features. Obviously, those features are defined as a response to requirements or problems. In this stage, team members try to understand the root problem addressed by requirements and to identify why those needs are qualified as a requirement. Then they will try to suggest some alternative solutions for that problem and to check if the listed features enable the final product to cover the requirements or not. Finally, they will decide about the best solution that will satisfy requirements as well as business goal and companies' capabilities[9, 10, 12]. Even if the organization decided to design different parts of product separately, for this stage it is necessary to see the product as a whole to ensure that all the considered features are helpful to achieve organization's goal and vision. The goal of the concept design phase is to identify and select the general type of solution required and not to focus on design and implementation details. The result is a documented design approach to successfully solve the root problem in a manner consistent with the requirements [10].

The creative and investigative aspect of the concept design process is the most significant opportunity for innovation during the entire new product development process[15]. Understanding the root problem independent of any specific technology and

then applying creative thinking to alternative solutions facilitates innovative designs. Concept design can identify areas where innovation is required.

#### 2.1.3.4 Testing

During the design test stage, design team members will build and test a couple of prototypes. Although these prototypes are not made from production components, they represent the product as closely as possible to the actual final product. These prototypes enable designers to determine whether the performance of the product matches the defined specifications or not. It will also help them to identify any probable issues with the design and provide them with an opportunity to gain field experience with the product. Then, more accurate prototypes will be built from the first production components received from suppliers to experience the actual design[12].

#### 2.1.3.5 Detail Design

Detail design or design for manufacture, is the stage that refers to the recognition of the interaction between the product design and the manufacturing section [16]. During this phase, according to the results of the prior steps, design team will identify and engineer the required parts. Tolerance, materials, and finishes are defined, and the design is documented with drawings or computer files [12]. In this step, any kind of information that is needed for the manufacturer will be provided by design teams and even some samples will be built to check any incompatibility between design and manufacturing process. Some ideas might seem attractive, beneficial, and applicable at the time of the design, while during the real manufacturing process and after reviewing the actual final product, design team might found them impractical or crude to be implemented. In this case, design team will review the whole design concept for alternative solutions and

features [10]. Consequently, this step help organizations to prevent from wasting time, money, and resources by reworking and helping them to recognize the problems before generating the final product at the industrial scale and in huge amount for market demand.

### 2.1.4 Approval

After accomplishing the design steps, and before new product delivery stage, an important stage is, attaining the approval. According to the product and type of organization, this approval process can be done by suppliers, investors, financial department, etc. The purpose of any production approval process is [9, 12]:

- To ensure that the designed part can meet the manufacturability requirements and quality requirements that are expected by suppliers.
- To provide evidence that the customer requirements and specification requirements are clearly covered with designed part
- To demonstrate that the design product has the potential to generate adequate amount of profit and it will help organization to achieve its business goal.
- To ensure the new product will satisfy all the safety requirements.

### 2.1.5 Delivery

In this stage the company will release the final new developed product after months of effort. The delivery stage includes the identification of appropriate suppliers based on the area that new product is generated in and the new product pricing process. In this step, according to the time and cost that were spent for developing the new product, the potential market, competitors' condition, expected return on investment (ROI), and value analysis, marketing specialists will offer a reasonable price for the new

product [12]. They will also forecast and suggest an appropriate alternative price in the cases that the customers' demand fluctuates due to either an increase or reduction in the market demand.

## 2.2 Lean New Product Development

### 2.2.1 Basic Concepts in Lean Management

Lean is a philosophy that helps organizations to improve their performance. The concept of value and waste are the key concepts of lean [17]. A value-adding activity is one that the customer, internal or external, considers to be completely worthwhile[18]. Value-adding activities are therefore those that either transform materials into products or sub-products, or produce valuable information or services that a customer will pay for. All other activities should be considered likely to be non-value adding[18]. An accurate definition of value and waste is useful to help organizations to implement lean practices more appropriately.

#### 2.2.1.1 Value

In Lean practices, the most emphasis is on the value adding activities. However, to identify value-adding activities and differentiating them from wastes, organizations need to understand a clear meaning of value. In the first step, organizations need to know their market and how their competitors are likely to react [17, 18]. When the goal is to deliver the best possible customer value among the competitors, it is essential to know the customers. Another point that requires the organization's attention is that the customers will make the final decision about the product. In other words, customers are going to choose what they want and what they like. In a real market, there are a lot of information about each product and customers cannot consider all the information to

evaluate the products to make their decision. Consequently, customers will put a bunch of information together and will classify all the information into three different bundles. The first bundle corresponds to all sorts of operation factors including reliability, service, price, and delivery. The second bundle is more related to product features or designs including innovation, styles, attributes, and technology. The third bundle is whether the product satisfies their requirements and expectations or not[19]. Customers will score each of these bundles in their mind for each product and they will pick the product that has the best score in one bundle and it is good enough in the other two bundles. Consequently, to be successful, organizations should not be perfect in all of the bundles[19]. Customers will not pick a product that is perfect in all dimensions. For instance, a customer who cares about the price and looks for cheap product will not choose a product that has kind of a good price. They will choose a product which has the least price while it is good enough in other bundles. The same applies for those care about the designs; they will choose a product which has the best available design and it is good enough in other bundles[19]. Following this strategy helps organization to guarantee customer satisfaction.

To understand how to define a “good enough” attribute that a product need to have for two of the bundles, the term “fair value” should be defined[19]. Figure 2 shows a value map diagram that help designers to become more familiar with the concept of fair value.

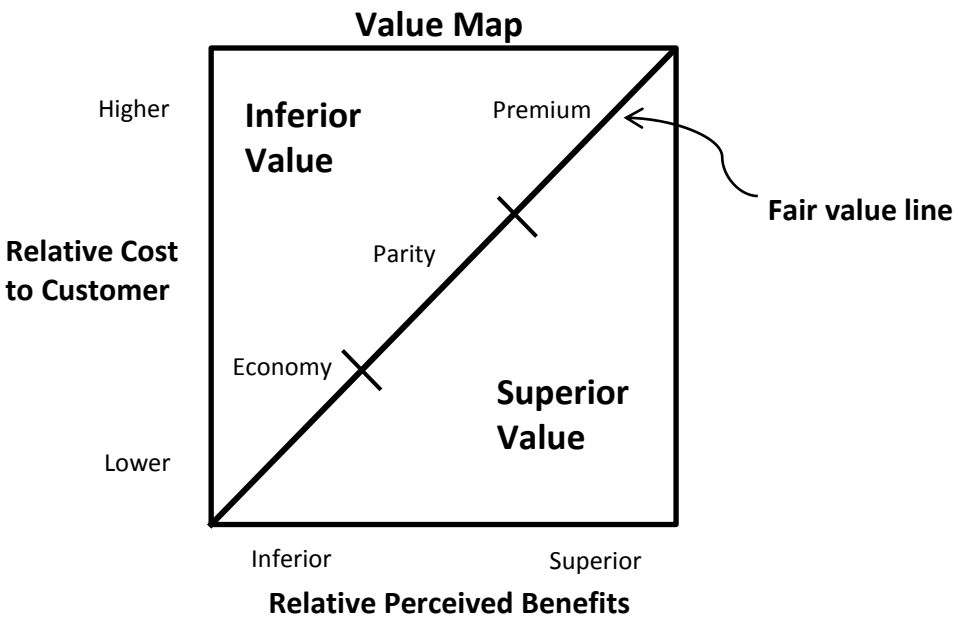


Figure 2 Value Map Diagram [15]

Value map indicates that if the organizations offer more benefits, the customers are willing to pay a higher price, and if the organizations charge customers for less price, they expect fewer benefits as long as what the product offers appears to be fair for them[19]. In order to be successful, organizations need to offer the fair value in two dimensions and offer superior value in one dimension. But the problem is that the fair value is not consistent[19]. In today's competitive market, by fast pace progression in technology and improvement in products, customers' expectations increase and the fair value line will shift to the lower right in the value map figure which means that a superior value condition in today market can be a fair value in the close future in the same market[19]. It shows the importance of product development process in todays' competitive market. The fair value line is a dynamic line which varies by time. This strategy will help companies to find a better meaning of customer value.

#### 2.2.1.2 Waste

Any information and activity that do not add value to the system and customers will be considered as waste[18, 20]. It can be in the form of unnecessary or useless time and effort or inappropriate performance measurement system, or many other forms. Different researchers based on their specific era have represented different classification for wastes. Womack et.al categorized wastes into two large groups [20]:

- Non-value added activities (NVA)
- Required none-value added activities (RNVA)

Muda, the Japanese term for waste is classified into seven different categories [21]:

- Overproduction which is producing more items than customers' demands
- Unnecessary transportation that does not add value to final output
- Redundant inventory, whether as finish goods or work-in-process
- Waiting time for any kind of resources across the value stream
- Reworking which means not being right at the first time and the need for allocating more resources (people, time, and budget) for revising.
- Over-processing that does not add value to final deliverables.
- Unnecessary human motion that does not add value to the final product.

According the area that the lean practices are going to be implemented, the waste classification may differ. For instance Ronald Mascitelli classified product development wastes into ten different types[22]:

- Lack of system discipline
- Waiting
- Transaction waste

- Hands of or transfer of process between people
- Re-invention waste
- External quality enforcement
- Over-process and over design
- Lack of effective communication
- Too many meetings
- Concurrent process that are unsynchronized

The more the information about the area that lean practices are going to be applied, the more specified and detailed waste classification can be. After identifying values and wastes, an appropriate practical strategy need to be developed. Implementing the developed strategy will enhance the organization performance through making it leaner. In general it can be interpreted from above classification that wastes are any item that uses available resources but does not add value to the system in a way to satisfy the customer value.

As mentioned, lean thinking is based on some prior idea like Kaizen, Just in Time (JIT), and Total Quality Management (TQM). One of the key elements of lean that has been introduced by TQM is producing high quality products at relatively low cost[18]. Quality can be defined as providing the exact product or service that can satisfy customers' requirements, no more, no less. However, these requirements need to be provided at the right time and the right price. Quality measurement is an aspect of TQM that is essential for lean environment. Quality management approaches across with process capability techniques will reduce the variability of the outcomes and increase their quality[18].

It is necessary to consider some process control methods to measure the quality of a system. For instance, a controller system can periodically check the correctness of information about customer requirement and apply any required revision and update. It can also make an environment within the organization that enables the employees to ensure that each process step supplies free-defect outcomes to the next step[23]. TQM also emphasize on the importance of continuous improvement or Kaizen which is essential in lean organization. Organizations need to map their value stream and analyze each step to identify and remove wastes. This process needs to be repeated incrementally, which means in each analysis step, the current wastes and bottlenecks of the system need to be identified and eliminated and then the system need to be analyzed again to find the new bottlenecks[18]. This incremental evaluation and waste elimination process will cause continuous improvement which results in high quality deliverables.

### 2.2.2 Lean Product Development Process

As mentioned, product development process results in a final product with new additional features and attributes. However, to complete a product development successfully, it is important to identify needs and requirements. In traditional product development, organizations try to develop their product for the sake of development. To be successful, organizations need to keep continuous improvement in the soul of their strategies; but at the same time, it is necessary for them to generate and improve products that correspond to users' requirements [24]. In traditional approach of new product development, companies designed products with additional features and then look for any potential customer for their new products or services. While it is obvious people do not pay for additional features, they tend to pay for something that will provide them some

benefits. Organizations need to understand the fact that customers differentiate between extra features and beneficial features[6]. Consequently, new product development can be described as the transformation of customers' requirements into a product or service that satisfy those needs. Companies and organizations need to investigate potential problems in their existing product or their customer requirements and then find solutions and alternatives for them. Their new product must be a response to a demand not just for the sake of designing something new.

The lean new product development (LNPD) process can be summarized as shown in Figure 3.

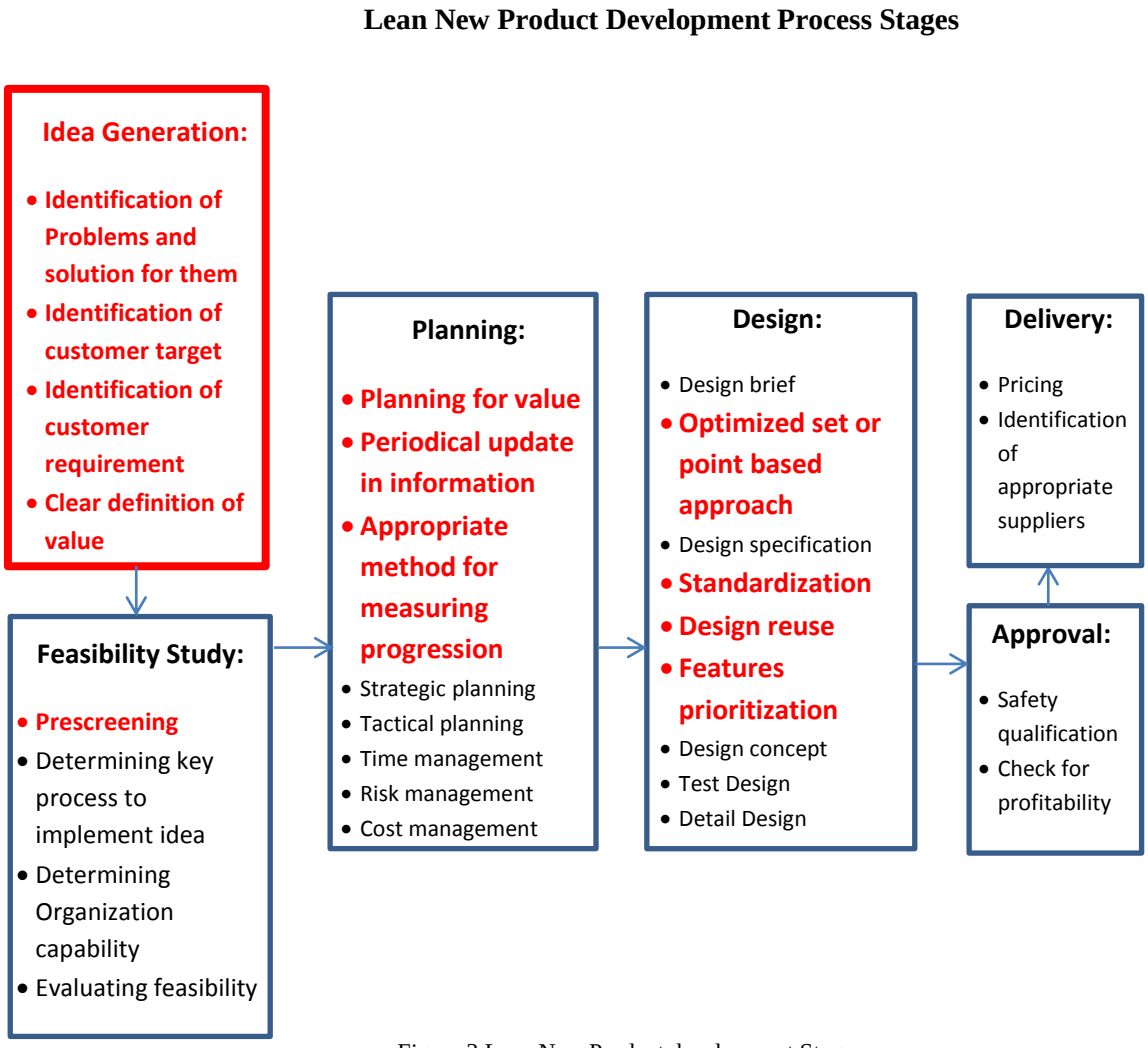


Figure 3 Lean New Product development Stages

In comparing traditional and lean new product development processes we can see some significant differences. Lean new product development has the additional step of idea generation including identification of problems, customer target, customers' requirements and clear definition of value. In feasibility study of the lean product development, instead of beginning the study from the scratch, organizations should start with a prescreening of other competitors. Planning for the value, periodical updates during the development process, and definition of proper methods to measure progression are three main differences of lean and traditional development process in planning stage. In the design stage in LNPD there are some additional steps including standardization, design reuse, and features prioritization. Approval and delivery stages are almost the same in traditional and lean new product development processes.

#### 2.2.2.1 Lean Feasibility study

Feasibility study might require the allocation of significant budget and time. In order to reduce the consumed time and budget for feasibility study, one of the appropriate ways is prescreening the ideas. Prescreening means identifying competitors with the same or close capabilities and determine if they are working on something similar or not. In the case that they generated the same product or provided the same service, the organizations need to find the answers to these questions: how much market share they have, what are the expectations of their customers, how much resources they spent, how long their product development cycle took. The more information that organizations attain about their competitors, the less time and cost they need to spend on the feasibility study [25]. It should be noted that prescreening might not be applicable to the products and services that belong to an entirely new area.

#### 2.2.2.2 Lean planning

At the start point, organizations planned based on their current knowledge. However, during the implementation of the development, some information might change. In traditional approach of NPD most organizations do a poor job of capturing and disseminating new knowledge and information. The lack of knowledge or using poor or inadequate information will increase the probability of mistakes and waste of time, money, and resources [26, 27]. While in LNPD organizations need to update their information about the process in short periods of time.

The other important issue about NPD is that in this approach, organizations plan their strategies based on the world view that they have. They planed tasks and process to achieve what they want. While in LNPD, organizations need to plan based on their customers' view and they need to define tasks that help them to achieve their customers' requirements[18].

In the traditional way of progress reporting that is used in the traditional approach of NPD, the progress is measured according to the amount of work or investments that is already done, relative to the amount they still need to do. This approach encourages design teams to start tasks at their earliest time to show that the progression percentage is well. In the other words they will start the development process without sufficient focus. In this approach design team members do not consider the importance of the tasks and appropriate time to start them which is good for the whole procedure [28, 29]. In addition, measurements should direct managers to the tasks that need their attention. The traditional approach of process progress report encourages them to ignore the tasks that have problems and move on with the tasks that they can easily perform to show

progression, but all these tasks will merge together at the end of process. Therefore, design teams need to stop and accomplish those tasks that had difficulties. This will decrease the probability of failure of the new product development process. In LNPD the progression of the process will be determined by comparing the results with short term goal that were defined at the beginning of the planning to help the development team to understand the situation compare to those goals [27].

In traditional approach of NPD, development team maps the process and analyzes each step for improvement. This improvement can be in form of adding new features or enhancing the performance of existing features. However, continuous improvement is essential for organizations success and it is important to start it from bottlenecks. In LNPD, the bottleneck needs to be identified for improvement. Any improvement in other tasks rather than the bottleneck will not have any effect on performance of the whole process. After improving the bottleneck task, that task will not be considered as bottleneck any more, and the bottleneck will change to another task which requires resolution and in this manner, the procedure of continuous improvement will be accomplished [29]. This will help organization to spend less time, budget, and resources since they need to only spend them, where they are required and specifically for the bottleneck task and not for all of the tasks within the process.

In summary, In LNPD, organization will focus more in execution and delivering value instead of defining a certain firm plan and controlling that plan. It does not mean that planning and controlling was not important for them, it was less important than execution and they spent most of their time on executing compare to planning. There was not any certain schedule or planning for their activities. They crafted the vision of what

they wanted to design and then managed their activities according to the fact that they need to be value added [30]. They spend most of their time to communicate information, designing and testing product according to the vision and less on the firm scheduling.

#### 2.2.2.3 Design

There are two different approaches for the design stage in new product development: Point based approach and set based approach [31]. In the point based approach, the design team will design the whole product at the same time. All the design steps that were described in the previous sections will be done at the same time [31]. The design team members all together will define the design description and specifications. Then they will do the concept design and testing, and finally the detailed designs. This kind of approach seems to be inefficient. There are a lot of time wasting and additional costs because of the longer design process and inappropriate usage of human resources. In this approach there is not any concurrent engineering which means doing some steps in parallel. In set based approach, the whole system will be divided into some subsystems. Also, the design team will be classified into some different category in which they are knowledgeable [31]. Then each team will individually design the subsystem that was assigned to them. Each team will have its own vision, specification, prototype, testing process, etc.

Some authors like Endris et al. claim that the set based approach is more lean and efficient. They believe, in this approach, the different parts of the product will be designed at the same time and in parallel to other parts and it will help organization to save a significant amount of time during the development process. However, there is another important point that organizations need to consider. When each of the teams are

done with their designs an integration process is needed. Since the teams accomplished their designs individually during the development process there might be some contradictions in different teams' designs or at least some problems in synchronization process which will waste a significant fraction of the time that had been saved due to concurrent engineering. To prevent this problem it is important to assume some intermediates between design teams and set more frequent meetings to update teams' information about other parts' designs. Besides requiring some budget, increasing the number of intermediates might increase the probability of mistakes and wastes, since the probability of sending information or documents to wrong teams will increase [25]. Consequently, it seems that an optimized approach between the set and point based will be needed depending on the case. Design teams need to be more agile, they need to decide between these two approaches or some combination of them based on the product they are going to develop.

#### 2.2.2.3.1 Design specification

In LNPD, researchers of design teams will identify customer needs. They will identify needs through conducting surveys, asking for feedbacks, face to face interviews with existing and potential purchasers, focused groups, and tracking similar products of competitors. They will provide a list of needs that will include latent need that are needs that customers may not be aware of them or problems they simply accept without any question, as well as explicit needs that are needs that will most likely be reported by existing customers [6]. Researchers develop the necessary information on which the performance, size, weight, service life, and other specifications of the product will be based. Customer needs and product specifications are organized into a hierarchical list

with a comparative rating value given to each need and specification. Based on the rating that each of the specification will get the design team will rank the features for implementation [24]. In LNPD this prioritization and rating will be based on the customer viewpoints and not based on organization's viewpoint.

A wrong stigma in traditional product development approach is the more, the better while with today's highly competitive markets and fast pace of improvement in competitors' products, organization should optimize their costs and also reduce the development lifecycle. The more might be the better, but the longer development time will cause to lose the market share. It will also cause more investment, therefore to increase the profit, the price of final product will be relatively high that will have negative impact on customers' willingness to choose this product or service [30]. In addition, in LNPD approach, organizations need to review their prior designs; they need to maximize the design reuse fraction while in traditional NPD approach there was no emphasis on this important point. Using prior designs and features that the company had spent resources, time, and money on will help the company to reduce the cost and elapsed time.

#### 2.2.2.3.2 Design concept

In LNPD, while in some cases producing some actual samples of the final product is inevitable, LNPD suggests that the organizations should minimize the needs for generating actual product samples; instead manufacturers and developers can use three dimensional solid modeling using programs such as "Pro-Engineer" or "Solidworks". Once the database has been developed, prototype components can be rapidly built on computerized machines such as "CNC", fused deposition modeling devices, or stereo

lithography systems [28, 29]. Using software and simulators in design process is highly recommended in LNPD. In the detail design step in LNPD the intention is to transfer all the required information for manufacturing, as well as transferring the information necessary to minimize the costs and resources that are used for manufacturing a new product. In other words the optimization of manufacturing process need to be done in design process since most of the wastes in manufacturing steps are rooted in the design procedure. Simplification of product design, minimizing parts count, and also trying to design product for existing manufacturing line are some common ways that can help to have more efficient manufacturing process [24].

#### 2.2.2.3.3 Standardization

Standardization step in LNPD is as crucial as all the other steps in design stage. Standardization helps to identify how the process should be completed by sequencing all the tasks and eliminating non-value added activities. The standardization approach can be applied to the parts used in the product design or the tasks in the design processes. Simplifying the processes is a great way to reduce the probability of variability during the procedure. The less variability a system has the less probability of mistakes and wastes it will have [27]. Changes during the design process means that, a significant amount of time, money, and resources that have been used until then were useless and an update in information is essential. A formalized system with defined structure is less prone to variability; however it is necessary to be aware of the latent problem that might occur because of a firm structure [31].

## 2.3 Lean Product Design

As mentioned, product design is one of the most important stages of product development process. Lean product design means to apply lean practices into product design stage. Stephan Emmitt described lean product design as improving the quality of services and products that are delivered to customers [32, 33]. Javier Freire and Luis Alarcon described the four stages necessary to produce improvements and changes as: Diagnosis/evaluation, changes implementation, control, and standardization and stated that an integration of lean thinking practices with these steps can be considered as a lean product design process [34]. Ballard and Koskela emphasized on the importance of uncertainties [32]. A design process which was less prone to uncertainties and is able to keep its pace without relentless pressure to reduce cost and time can be defined as a lean product design process [32]. Formoso et al. believed effective communication, adequate documentation, efficient input information, balanced resource allocation, and proper decision making are important keys that can enable organizations to lean their design process [34]. Bagley and Lewis described lean product design process as a process that generates value for customers and removing the wastes [35]. Martinez and Farris emphasized on a steady need for a fast and less costly product design (PD) process which will provide a high quality outcome [36]. Karlsson and Ahlstrom focused on the importance of fewer errors during the PD process [36]. Chen and Taylor identified standardization, design for manufacturing, and value analysis as key components that help companies to enhance their design performance [37]. There were a lot of description and definition that was explained by numerous authors and researchers. Based on the literature review performed for this work, although most of those studies referred to

proper points and in general they talked about the same concepts, but lack of a consensus definition of lean product design was obvious.

In addition, there was not any measurement tool that enables organizations to evaluate their design process. Each of the studies offered some useful factors to make product design process leaner, but there was not any comprehensive list of factors that organizations can use to measure their design process performance. Consequently, a gap was found in the appropriate and precise definition of lean product design and a lean product design measurement matrix. In this research I tried to identify a comprehensive list of measurement factors to facilitate the PD evaluation process.

CHAPTER 3

# RESEARCH QUESTION AND RESEARCH METHOD

## 3.1 Research Question

A successful new product development process can lead to a successful business. The new product development is integrated to the ability of a business to remain competitive in today's market with rapid pace of changes in technologies and customer requirements. In today's market the development process time is just as important as the existence of development process. In other words, a delayed or slow new product development process will have the same result as the absence of new product development. Another aspect of new product development can be seen in the fact that users are looking for more innovative products and organizations that offer their customers more inventive products and services could be the leader in their industries. The most difficult challenge for different companies is to find an appropriate balance between their product life cycle and their new product development time. If their product life span becomes shorter than their new product development time, that company will encounter serious problems in the future and they will lose their market share to the competitors. Consequently, it is essential for all the companies to make their NPD process leaner. The first step in this procedure is to understand different factors that have impact on the NPD performance of an organization.

As discussed in chapter 2, there is a lack of consensus in definition of lean product design; and also there is not any in detailed list of important factors in this process. Consequently, based on the information that I obtained through an immersive

literature review, in this thesis I will identify those important factors while determining certain measurements corresponding to each of them to enable companies to evaluate their performance.

### 3.2 Research Method

My review of the lean new product development and lean product design literature will start with a "read through" of books on LNPD and LPD, e.g., [5] and [54], and frequently quoted articles on LNPD and LPD, e.g., [3] and [51]. This will allow me to establish the most relevant keywords, which were employed in the subsequent formal search for related literature. I will search for articles based on the following keywords: "Lean Management," "Lean Concept," "Lean Product Design," "Lean Design," and "Lean Product Development" or "Lean" in combination with "development" or "designing". The literature search will be accomplished through databases including: *Academic OneFile, Academic Search Premier, Business Source Premier, IEEE Xplore, Sage, Compendex, Science Direct, Springer, and Wiley*. Together, these databases contain all major journals publishing articles on LNPD and LPD.

Initially, the articles found will be broad, and therefore, I will skim through the abstract and conclusion of articles to determine whether to include a certain one for review. This will generate a first tentative list of literature. In this round several articles will be excluded from the list since they might only discuss the lean concept or lean manufacturing and not necessarily LNPD and LPD. Next, I will go through all the remaining articles for a second round of filtration. Some of the articles might only cover the general steps and principles of LNPD and LPD, which means there will not be any clear definition of lean design or a list of factors that have impact on leanity of new

product development or product design process of companies. Consequently, I will exclude those types of articles from my list. After creating a list from appropriate articles, I will begin reviewing all the remaining articles in detail to extract all of the effective factors that may have an impact on the lean design process. Finally, I will develop specific measurements corresponding to each of the founded factors in order to make the qualitative factors of the lean design process more quantitative; and as a result, more sensible.

After developing the measurement matrix I will design the online survey questions. Depending on the amount of required information, I will design one or a couple of questions corresponding to each of the developed measurements. In order to have a survey which will provide me reliable, accurate, and applicable results there are several points that I need to consider during designing the survey questions.

The first point is to avoid asking about more than one subject in one question or statement. For instance, I need to ask respondents about the quality and quantity of their information about their customers. Each of the subjects, "quantity of information" and "quality of information", should be asked in a separate question. Another common mistake in designing survey questions is to use leading questions. A leading question is one which attempts to guide the respondents' answers. All the statements and questions need to be designed in a way to ask the point of the statement indirectly and both the respondents and designers should not feel any advantages in choosing a specific choice or option. The next frequent mistake in designing surveys is to use words that have vague meanings that can be interpreted differently by different respondents. Using words with

relative meanings such as frequent, good, high, cheaper, etc. can be an example of this type of mistake.

Another important aspect of designing survey questions is to use a combination of different types of questions based on the information to be collected. There are several types of questions including open-ended, close-ended, yes/no questions, likert system, multiple choice, fill in the blank, etc. Open-ended questions are the least preferred type of question since they take more time from respondents and they only should be used when they are required. While people prefer "yes/no questions", in most cases it will not provide researchers with accurate and reliable results and it would be better to use the likert system to be aware of the level of agreement or disagreement of respondents with a certain statement. To increase the response rate, I also need to minimize the number of questions.

CHAPTER 4

# DEVELOPING MEASUREMENT FACTORS FOR LEAN PRODUCT DESIGN

In this section, the presented measurement factors need to be investigated to evaluate the leanity of the design and development process of an organization.

## 4.1 Customer Satisfaction

As noted before, lean management focuses on customer values. The quality of a product is the most important element to achieve customer satisfaction [38, 39]. Products with a high degree of design that meets customers' needs is not guaranteed to be successful; however a product with low degree of design meets customers' needs will absolutely result in an unsuccessful market. Consequently, it is essential to ensure that the developed product or service satisfies customers' needs. After addressing problems with the current design of a product, new features that customers are willing to pay for can be added. The features considered for development need to be based on customers' demands and expectations and not for the sake of development [40]. The customers' requirements need to be identified, and correspondent features and attributes that can satisfy those expectations need to be added to the product.

Customers' needs include the expected features, a fair price, and proper release data [41]. A high quality product can be defined as a product with the maximum number of expected features, offered at a fair price and introduced at the right time. To satisfy all

the needs, organizations need to gather adequate amounts of information from proper sources [38, 39].

### 4.1.1 Information about Customers' Requirements

While various methods and tools were developed to increase quality, they mostly focus on cost and throughput time. It is important to acquire information about customers including: Who are the customers, what they do, why they need the product or service, how they will use the product, when they need it, how much money they are willing to pay for it, what aspect of the product make them feel good about, what their expectations are, how they think about competitors' products, etc. [42].

The more specified who the target customers are, the more detailed and accurate definition of value based on customers' expectations and requirements can be acquired. Adequate information about the ways that the product can be used by customers will help the company to see different aspects of product's usage to ensure that it will meet all the expectation and to resolve any probable problems with the product. Information about the time that users need product will help to release the developed product at the right time. Besides expected features and proper delivery time, customers are looking for a fair price. Companies need to identify the fair price of a product according to the customers' viewpoint. Information about the opinions of customers about competitors' products can help a company to identify its potential market. As well, they can focus on products of popular competitors to add advantages of competitors' products to their product [42]. These information help companies to have a clear understanding of users' requirements to design products that will satisfy their needs. Consequently, it will be easier for

organizations to prioritize the features that need to be considered for the final developed product.

The information about users' needs also help companies to define value and waste more appropriately. Any characteristic of product or any step in the design phase that is important for users and might increase their satisfaction will be considered as value [42]. In the same way any activity or attribute which will not result to customer satisfaction will be considered as waste. For example more information help companies to define more clear objectives and goals for their design teams which decrease the probability of deviation or change during the design phase since they are aware of the point that they want to achieve [42]. In this case, more information about users helped organization to prevent from wastes. These information also facilitate the process of planning based on the customers' view point which means a more accurate definition of value. Improving information about customers' needs cause quality improvement and lead to more customer satisfaction.

The information transformation from marketing team should not be limited only into the design steps. A continual flow of information through customers' feedback during the whole development and delivery process help design teams to improve features regard to users' values [42]. Different approaches that help organizations to acquire information about customers will be discussed in next section.

### 4.1.2 Appropriate Source to Gather Information about Users

Inappropriate source of information about customers' requirement will cause problem in the design process and may lead the companies in a completely wrong

direction [40, 41]. Consequently, gathering information from appropriate sources is critical.

Every new product has a life cycle that describes various stages of the market of that product over its lifetime. Each stage has different customers with different requirements and expectations. Different customers of a new developed product during it lifetime can be classified into: innovators, early adaptors, early majority, late majority, and laggards. By understanding the market segment and target customer correspond to it, organization's information becomes broader about customers' requirements. In the next step, for having more detailed information about customers' needs each organization should listen to customers' concerns and complaints in order to understand their desires and find out what are the features that they expect. As an example customers that are classified in early majority segment care more about quality, while laggards care more about the price, and innovators focus on features and applications. Consequently, a specific product cannot satisfy all different types of customers and it is essential to consider effective strategies to acquire accurate information about customers to identify the target customers and their needs. Different approaches that help organizations to acquire information about customers are listed below:

- *Developing Long-term Relationship with Customers:* Companies having long-term relationships with their customers are ahead in the competition. Giving benefits for existing customers would help companies develop a better relation with them. For instance, some companies offer a free product after a certain number of repurchases of a specific product. This can help establish a good relationship with the customers and allow companies to hear their customers more

clearly. This will also help companies attain useful information about the features that their customers expect from future product [9].

- *Making Customers a Part of the Design Process:* By asking customers for their feedback and suggestions in certain periods of time, companies can improve their information about customers' requirements. Companies can consider some of their current customers as developers by asking qualified customers to participate in the design process and help improve the products. Those customers can experience the developed product before the actual release date. As a result, useful feedback about the product can be provided to help the company resolve problems before product launching [9].
- *Ethnography Research or Camping Out:* This is another useful way to get information about customer needs. It includes camping out with customers or observing customers for extended periods, watching and probing how they use or misuse the products. According to an ideation survey that was conducted by Product Development Inc. among 160 US firms, ethnography provides the greatest insights into users' unmet and unarticulated needs, applications and problems. The depth and quality of knowledge and information it will provide is the main advantages of this method. The main disadvantage is the time and cost it takes to conduct such studies. By shortening the length of visit per customer and using advanced technologies like on-site video cameras, the time and cost of this process may be reduced [43].
- *Customer Visit Teams:* Customer visit team can also help companies to improve their information about their products' users. In this method cross-functional

teams visit customers and employ in-depth interviews to recognize user problems, needs and desires for new products. The major advantage of in-depth customer visits is the ability to identify customer problems and unspoken and latent needs. Since the interview questions are open-ended, they allow the opportunity for acquiring information that might not be gained by quantitative research. Finally, using cross-functional interview teams promotes a shared vision of what customers need and expect. The main challenges are getting customers to cooperate, finding the time to perform this study, training the interviewers and designing a robust interview guide [43].

- *Living the Customers' Experiences*: The design team members should put themselves in the shoes of the customers and realistically experience the products to find out about weaknesses and strengths of their products and services. This will help the team analyze and evaluate their products' performance based on the customers' viewpoint rather than designers' viewpoint and enable them to find out information that were blind to them [38, 44].
- *Customer Focus Group*: Customer focus group is a helpful method to detect problems that customers had experienced with products. In this method, focus groups are run with customers or users to identify needs, wants, problems and suggestions for new products. The focus group moderator skillfully focuses the discussion on problems or wants, and helps users walk through their problems. Challenges include getting the right customers to agree to participate, as well as the cost associated and possibly in finding the right moderator with focus group skills and product knowledge. Further, since the sample size of group attendees is

quite limited, potential biases may occur in the discussion due to one dominant person [43].

- *Lead-user Analysis:* The theory is that if one works with innovative customers, innovative product ideas are the result. The technique entails assembling a group of particularly innovative customers or users to recognize problems and potential solutions. The major challenges are identifying who the innovative or lead users are, getting them to participate in an off-site workshop, and then structuring and running the workshop session properly. This method is definitely recommended [43].

### 4.1.3 Quality of Communication between Marketing and Design Team

In most organizations the marketing department is responsible for gathering information about customers, and design team in engineering department is responsible for implementing features that satisfy customers' expectations. Consequently, the quality of flow of information between marketing and design teams has a great impact on the design [45]. The more smoothly information flows between the two teams, the more accurate information the design team will have about the customers which further leads to reduced mistakes, changes, and other type of wastes during the design process [46]. In some development projects the goal of marketing and design teams might be different or do not match perfectly. The first step to facilitate the communication between teams is to ensure that both teams share the same goal. Both teams need to participate in a meeting at the beginning of the project to check the long and short-term goals and plan for execution [45]. At the beginning of the design process, marketing team will provide adequate and accurate information about customers' expectations to help design team to prioritize

features that need to be added to the product. This communication needs to be continued and gradual update of information by marketing team during the design process is essential. To transfer new information between teams some frequent meetings need to happen throughout the development process.

Having information as quantitative as possible will make it easier to communicate accurately. For example, quality function deployment (QFD) is a structured approach to define customers' requirements and transform the qualitative demands into quantitative parameters for implementation in the design phase [47]. Besides, all reports between the design and marketing teams need to be comprehensive yet concise. They should concisely cover all aspects of the project. Any missing points can cause a change in design after manufacturing which is highly undesirable in a lean environment as more time and money will be wasted. In general, the more effective communication between design and marketing teams, the leaner the design process can be.

### 4.2 Cost and Time

Differentiating between value adding and non-value adding activities and identifying different sources of costs are two important steps to achieve lean product design [48]. Supporting and designing costs are two main sources of cost in the product development process. Usually, companies need to allocate an appropriate portion of their human resource, time, and money to identify their weaknesses and problems and then find proper strategies to improve them [44]. Resources spent this way are considered to have supporting costs. Besides, the money that companies need to spend to attain appropriate location, services, and software for their design team before the beginning of design activities are considered as supporting cost [49]. Some portion of the supporting

costs, like the ones spent to provide location, services, and tools are inevitable while the others spent on fixing defects or product redesigns should be avoided [49]. For the design cost, it includes money and any kind of resources that are consumed during the design phase that are convertible to money. Required information and human resources are two examples of inputs that companies usually spend money on during the design phase [48-51]. Technically, the less the design and supporting costs are while retaining features that satisfying the customers' expectation, the leaner the design process is. However, it is essential to differentiate costs that do not add value to the final product from costs that are necessary and value adding, though companies tend to focus on cost minimization to become lean [52].

Time is an important factor for business success, as it is a limited resource not possible to restore [44, 53]. Consequently, besides efficient usage of material, human resources, and information, organizations need to manage their time appropriately. Late delivery of products and services can be the result of inefficient usage of time that could cause problems like losing markets, gaining a bad reputation, and being over budget [49, 53-55]. To avoid delivering the product late, organizations need to shrink their product development life cycle. A significant fraction of product development time is consumed by design process and shrinking the design process time helps to reduce the overall product development time. Mapping the value stream in the design process and eliminating the non-value adding activities are helpful ways to reduce the design process time [41, 51, 54, 56].

There are different reasons for wasting time during the design phase, and they include: improper or unclear definition of the goal, postponing the problems, unrealistic

planning and estimation, ineffective communication and negative iteration [39, 52, 57]. If no clear goal is set at the beginning of design phase or when design issues are not resolved in a timely manner, unnecessary changes will need to happen during the design that waste time and money [57]. Although certain iterations are necessary for value generating during the design process, unnecessary iterations are considered as negative and should be eliminated. Correcting design errors is an example of negative iteration [41, 58].

Accelerating the design process will help a company to deliver its products within short time frame and ahead of its competitors. This further gives the company a chance to introduce its products and services to the early adaptors in the market and possibly get feedback [55, 59] to rectify any problems that need to be solved. Accelerating the design process also helps companies to respond to customers' orders faster and increase the overall flexibility [51, 54, 58]. According to the rapid pace of market changes, the prototype development time should be as short as possible since customer requirements might change during the periods of time.

Managing information inventory is a helpful strategy that helps organizations to avoid wasting time [57]. For this purpose, the non-value adding information should be identified and then be eliminated. Besides, information about prior and current design projects can be classified into clear subjects that help different design team members to find required information faster and more accurately. This process will facilitate the flow of information from one entity to the other and as a result facilitate the process of reusing prior information. Some other ways that help to decrease the design process time include [53]:

- Evaluating and employing technological methods like simulation software and automated instruments in design process at the right step.
- Identifying and removing unnecessary mediations ,whether they are people or systems
- Disseminating essential information and knowledge
- Identifying and eliminating parallel tasks during the design process

In general, the less time spent in development and design process, the more lean the organization NPD is. Next we discuss a few specific factors that influence the time and cost associated with the product design phase.

### 4.2.1 Variability of Outcomes

Reducing variability of outcomes in the design phase will help reduce the probability of wastes in the form of defect, overdesign, and over-specification [38, 58, 60, 61]. Reducing the variability of outcomes can be achieved thorough standardization. Standardization is a key component of lean product design and production that defines how the process is to be completed by sequencing all the value adding tasks while removing non-value adding activities [60, 62]. Defining clearer structure and establishing certain standards as well as employing part integration and simplification are all useful techniques to decrease variation during the design process [51, 60, 62, 63]. By simplifying and formalizing the design steps, the entire design and manufacturing process is less prone to variability. Using part integration can be useful to help team members reduce the complexity of design process [62]. Most of the problems in the manufacturing process are rooted in the design steps, and reduction of variation in the design process will significantly decrease the variation in the manufacturing process, and thus make both

the design and manufacturing processes lean [38]. In general, the less variability in the design process and the design outcomes, the leaner the process is.

#### 4.2.1.1 Reducing Unnecessary Complexity during the Design Process

In product design, the power of managing complexity is very important. Complexity of design process causes hidden costs that are not easy to identify. Pessoa, et al. introduced a helpful way to identify unnecessary complexity called the "Zero Base" approach [55, 63].In this approach company is suggested to begin the design process from scratch and analyze that of each product separately to identify the unnecessary and redundant steps in the process. Since "hands off" or intermediate steps, usually cause higher probability of complexity, failure, and cost, they need to be identified and removed [64]. Possible impacts from removing those steps then need to be re-evaluated by engineers. Besides redundant steps, using or storing unnecessary details is considered as a source of unnecessary complexity too. A periodical review of detailed information is also helpful to decrease or eliminate over-documentation to make the design process simpler and leaner [56].

### 4.2.2 Defects

Defects in manufacturing and designing represent any activity or result that prevents the process from being desirable, safe, and complete or in other words, prevents process outputs from being what customers expect [61]. Defects are a main type of waste in the lean concepts. Most of the time the defects that occur in the design process can be easily removed and this type of waste have much priority to be rectified.

While companies should try to minimize the mistakes and defects, it might be hard to eliminate them completely. The information about the future is restricted and

makes the project domain uncertain. This uncertain domain usually leads to unavoidable defects. Reasons that may increase the defects include [61]:

- Poorly managed fast design process: A fast design process may increase the probability of defects, but if managed appropriately it can also help correct mistakes occurred in the design process in a faster manner.
- Lack of discipline: The absence of a certain structure within the design teams and lack of clear understanding of roles and responsibilities will increase the probability of defects.
- Poor goal-setting: The lack of clear definition of goal to achieve will cause confusion for design team members that increase the probability of defect.
- Inappropriate amount of information: insufficient amount of information may lead design team to an incorrect feasibility study and/or profitability study that further result in defects in design.
- Inappropriate definition of value: A vague or inappropriate definition of value may cause team members to misunderstand value brought by individual tasks in the process and create defects that are not valued by customers.

The best way to eliminate defects is to believe in and apply the "Zero Defect" theory [58]. This theory is a kind of thinking procedure stating that any amount of defects is not acceptable and everyone should do things correctly at the first time to prevent spending time for more reviewing and correcting errors [58]. It emphasizes that all tasks should be done correctly without repeat and rework. Another name for it is "Right First Time."

Using more organized systems will help to decrease the defect rate too. Using open book management system that lets managers give proper information about strategies and tactical plans of the organization to the employees could help. Less manual data transfer and fewer interfaces decrease the probability of defects [54, 55]. Current and future state mapping can help identify some of the probable reasons of defects and thus avoid them.

#### 4.2.2.1 Selecting the Right Technology

Certain technological instruments and software can help the design phase be more accurate and reduce mistakes. Selecting and adopting the right technology to use during the design phase will help to decrease defects as well. To select the right technology, incorporation of experienced employees and young and talented employees who are familiar with new technologies and software is essential [40].

Overall, the fewer defects a design process produces, the less resources will be wasted, and thus the leaner the process is.

### 4.2.3 The Percentage of Design Re-uses

Some of the forces that drive NPD process are limited time, fast changes in technology and customer demands, and intensive competition. All of these factors make the efficient use of resources a necessity. Design reuse is one of the approaches that can help companies utilize their resources more efficiently. It is the process of reusing previously developed designs to make or improve new products and services [50, 56]. It helps to design and build new products with less effort, cost, and time. Design reuse will reduce cycle time, design errors, changing specifications, and poor compliance with research and development process. Designers and developers could use a design method

that has already been tested for reliability and well performance in their new project. In this way, companies can take advantage of proven designs and apply them for different purposes. Flores and his colleagues classified capability of design reuse into six different levels as shown in Figure 4 [39, 59].

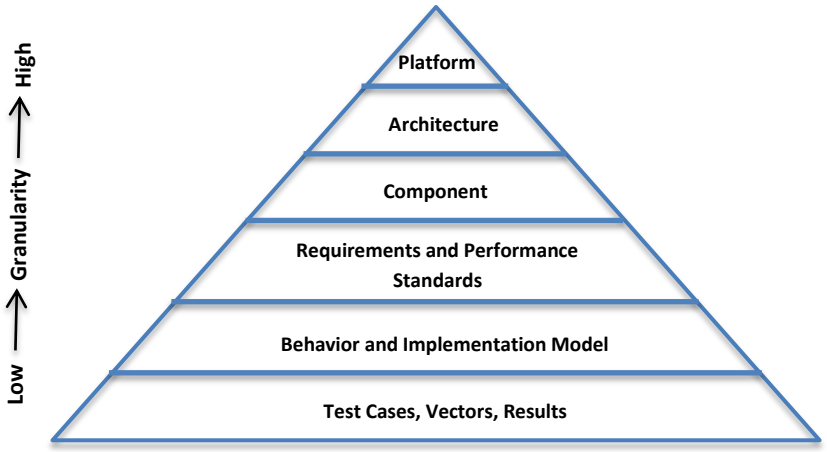


Figure 4 Reusability Diagram [59]

Platform can be described as the collection of assets, including component designs shared by similar but distinctive products[59]. Planning the product platform involves managing a basic tradeoff between distinctiveness and commonality[59]. On the one hand, there are market benefits from offering several distinctive versions of a product. On the other hand, there are design and manufacturing advantages to maximize the extent to which these different products share common components [59]. Design reuse at this level means extending an existing platform to design new product. It has different potential benefits including: reducing development and manufacturing cost, reducing development time, reducing systemic complexity, better learning across project, and improving ability to update project [59].

Product architecture is the arrangement of the functional elements of a certain product into physical blocks[59]. The purpose of product architecture is to define the

basic physical building blocks of the product in terms of both what they do and what their interfaces are with other parts. Product architecture can be categorized as "Modular" and "Integral". The architecture demonstrates which modules will be part of the system and what their functions will be [59]. Modules may be common across different products, but they may also be specific to any one product. Design reuse at this level means using modules from prior design to design a new product. Modularity provides some advantages including [59]:

- It allows the designer to control the degree that changes in processes or requirements might affect the final product
- By facilitating and promoting interchangeability, modularity gives designers more flexibility to meet changing processes
- Reduce in the life cycle costs by reducing the number of processes and reducing repetitive processes.

Reusing a component from prior designs in new ones is increasingly viewed by companies as a way to offer high variety in the market while retaining low variety in operations. The design reuse rate at the component level can be calculated as Eq.1 [53, 59].

$$\textit{Design Reuse} = \frac{\begin{array}{c}\textit{Number of parts or drawing developed for a given product}\\ \textit{That have been reused on other products and are in production}\end{array}}{\textit{Total number of parts or drawings developed for the given product}} \times 100\% \qquad \textit{Eq.1}$$

Requirements reuse is commonly defined as the process of analyzing, eliciting and managing requirements at a suitable abstraction level so that they can be reused in new systems [59]. Behavior and implementation models are next stage in the development process to capture users' requirements and implementation details. The

reuse of these models offers great value if modular models are designed based on singularized requirements and parameterized to absorb product specific variability [59].

Even in a system with large number of functions that all perform flawlessly; only one mistake can be catastrophic in a procedure. In order to carry out thorough testing for increasingly complex systems, huge amount of resources will be needed to test each system's iterations during the development process. To decrease the time and resources consumed for testing, alternate ways such as testing automation and testing reuse are developed [59]. Design reuse at the testing level means capturing and reusing common test patterns or using tests that were performed in prior designs to test current designs.

Design reuse is considered primarily in three dimensions. The first dimension is along the process chain and goes deeply into the design. The second dimension is along the time, between different versions, to revalidate a new version with playback of prerecorded test cases and comparison of results against expected test results. The third dimension is in the form of test cases, test results, test vectors, and across different production lines[59]. Based on the level of common functionality of product lines, a large number of test cases, test scripts and accepted output can be reused to help companies save time [59].

In general, increasing the percentage of design reuse increases the leanness of a new product design process.

### 4.2.4 Design Change after Release to Manufacture

Design change after manufacturing can be considered as a type of waste. Increasing the number of design changes before manufacturing and during the design process may be an indication of innovation and improvement based on updated

information. However, the number of design changes after manufacturing and before release should be minimized, or at least the ratio of number of design changes after manufacturing to the total number of design changes should be decreased. Large numbers of design changes after manufacturing are considered as overdesign and it is considered as a waste of time and budget [50, 56].

$$\textit{Design Change after manufacturing} = \frac{\textit{Number of design changes after release to manufacture}}{\textit{Total number of design changes}} \times 100\% \qquad \textit{Eq.2}$$

Design change due to company error or over-specification obviously would be a waste within company [60]. The number of design changes due to specification change introduced by engineer should be minimized. Improving the information about customers' needs can descend design changes due to company error. We design team members are aware of requirements of users they can define value, goal, and vision more clearly which decrease the probability of change in specifications. As shown below, Design Change Index represents the ratio of design changes due to specification change or company error to the total number of design changes [50].

$$\textit{Design Change index} = \frac{\textit{Number of design changes due to specification change or company error}}{\textit{Total number of design changes post critical design review or release to manufacturing}} \times 100\% \qquad \textit{Eq.3}$$

Two effective solutions that will help firms to prevent repeating the mistakes and wasting time and other resources are [56]:

- Simulating the design process and final product
- Disseminating the knowledge and information through different members of design team

Among the different types of design changes, design change due to specification change introduced by engineers is considered as design over-specification. Improving the

quality of information about customers' needs can help prevent design changes due to this reason.

In summary, to be lean in the product design process, the number of design changes after manufacturing and before product release need to be minimized.

### 4.2.5 Effective Communication

Communication is an essential part of daily work a product designer has in a company. Effective communication across organization is essential to the success of everyone's job and helps avoid deviations from the organizational goals [65]. The first step to have effective communication within the organization is to understand the organization's culture, plans, and objectives clearly. For the product design team, besides understanding the organization's overall vision and mission, team members need to understand everyone's responsibilities within the team to avoid poor system connectivity [53, 60]. Poor system connectivity means involving too many sources, systems, and data when it is not necessary for project accomplishment or excluding sources, systems, and data that were required to be involved [56, 58]. When too many systems are involved, extraneous manual intervention may happen and the probability of sending information to the wrong place may increase. When essential systems are excluded, problems in disseminating required information and useful knowledge among employees will occur and lead to inappropriate decisions.

To facilitate effective communication, certain technologies can be adopted. For example, electronic grapevines, which represent the usage of online media in businesses, are tools that facilitate electronic communication [56, 58]. The use of public or private forums can create environment more comfortable for employees to give feedback and

possibly share bad news about the design process. Electronic grapevine tools can be used internally or externally in an organization [56]. Some of the examples of internal uses are: cloud, email archiving and continuity, virtualization, etc. Overall purpose is to share, transfer, store, archive, backup and protect information within an organization.

#### 4.2.5.1 Horizontal Communication among Departments

Cooperative effort of more than one department is required for being successful in business organizations. This will show the importance of effective communication between people who work for different teams and departments like design and manufacturing teams. When a message is being transferred via multiple parties, it can easily get distorted [40, 41]. As a result, eliminating the intermediate, or middlemen, in transferring information can help decrease the chances of misinterpretation. Direct communication between teams should be encouraged. Also, strategies that facilitate communication among different departments can be employed, and they include [65]:

- Filter information that should be send to other team and be concise
- Avoid using jargon and special languages
- Ensure that both teams in conversation have same goal
- Do not ignore other team's efforts and goals
- Consider certain rules and channels for communication like monthly meetings or weekly online meetings
- Using advanced technology and software to facilitate information flow
- Resolve any probable conflict as soon as possible
- Listen carefully to others and give them nonverbal signals

#### 4.2.5.2 Communication within the Design Teams

The overall performance of design teams highly depends on how well the team members communicate with each other. Frequent meetings to share information and make decisions can help build a positive environment within the design team [66]. Point based and set base are two approaches for product design. In point based approach all the members work on a same process and continue it step by step. In set based approach, the design team members will be divided into sub-teams and each sub-team will work on a specific design. When the sub-teams are done with their design, parts will be integrated together to be the final design. Effective communication is vital for success in the set based approach and obviously problems in communication or lack of communication may result in designs not aligning with each other and thus lead to failure.

#### 4.2.6.1 Design for manufacturability (DFM)

As mentioned earlier, one of the key elements of lean is to reduce the variation in order to increase the quality of products and services. A large fraction of variations in manufacturing can actually traced back to the design phase. As a result, it is important to recognize the close interaction between product design and manufacturing within a company [67]. Design for manufacturability (DFM) is an element of lean design that helps simplify product designs, minimize the required resources and costs, reduce the number of parts, and most importantly, ensure the compatibility of new designs with existing manufacturing processes [37].

Assembling different parts of a product is one of the most challenging procedures in product development and manufacturing. Incompatible and unsynchronized parts that are usually designed by different design teams increase the amount of wasted resources.

Consequently, it will be useful to decrease the number of parts through part integration. Part integration reduces the need for unnecessary assembly and also promotes the design of parts with multifunctional features that enable engineers to use them in different products to increase design reuse [68]. Part integration along with simplification helps improve the efficiency and quality while reducing the variability in design. In addition, the use of standardized materials and parts also help ensure the compatibility of design with existing manufacturing facility, simplify the design process, and reduce outcome variability.

#### 4.2.6.2 Value analysis

Value is embedded in the attributes and features of products that customers are willing to pay. Companies can evaluate their customers' perspective to identify what features they expect a product to have. Kano model analysis is a useful technique that helps the design team to prioritize product features [69]. The model classifies features of a product or service into three different categories—threshold, performance, and excitement [69]. Threshold category includes the features that customers expect to be present in a product or service; Performance category includes the features that are not absolutely essential, but are aware by the customers and can enhance customers' enjoyment of the product or service; Excitement category includes features that customers are not familiar with and do not know if they want them, but can make the customers pleasant once they identify them [69].

It should be noted that the relationship between customer satisfaction and product features is not linear in all the categories. As depicted by Figure 5, a change in product function from level A to level B has higher impact on the change of customer satisfaction

level in performance type features ($y_2 > y_1 \sim y_3$) [69]. It can also be seen that the absence of threshold features can cause customer dissatisfaction while fully implementing threshold features do not necessarily cause customer satisfaction. To satisfy customers, products need to have features that fall into the performance or excitement categories.

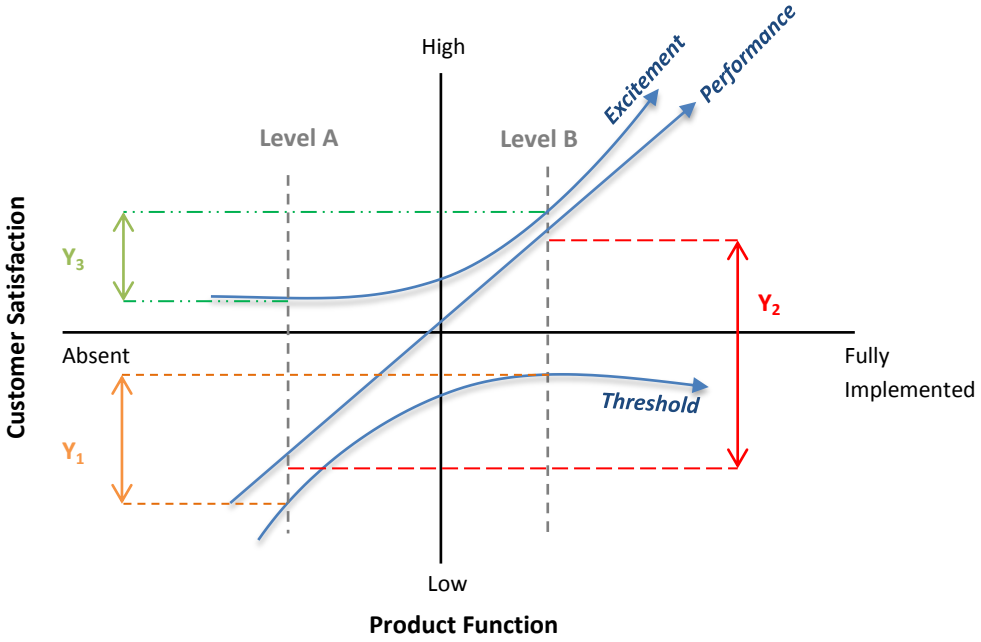


Figure 5 Kano Model of Customer Satisfaction [66]

In order to prioritize features to be included in the design of a product, appropriate and adequate information about customers' expectations need to be gathered and assigned into one of the three categories. Products need to have all thresholds, maximized performances, and provide as many as possible excitements. Since all the features a product can have are associated with development costs, the ones that customers do not care about need to be identified and eliminated. With limited resources, the associated cost together with the degree of importance of features wanted also need to be prioritized to decide which to be implemented. The value analysis in lean product design means matching customer expectations with product design and prioritizing features base on their criticality and cost.

## 4.3 Lean Design Measurement matrix

To test the results that were extracted through a comprehensive literature review, key measurements for lean product design were developed. According to the developed measurements online survey questionnaire were constructed. Each of the survey questions were designed based on the supportive information that were attained from literature for each of the key measurements. By interpreting the results of the survey for each company, their new product design process could be evaluated regarding lean. All of the lean measurements and corresponding survey questions are explained in the following section.

### 4.3.1 Measurement Corresponding to the Variables of Customers' Information

To investigate the impact of customers' information on leanness of the design process of a company, measurements for variables related to customers' information are developed. The main variables of customers' information for lean product design include the quality and quantity of information about customers, variety of sources to attain information about customers, and quality of communication between the design and marketing teams.

For the first variable, an adequate amount of high quality information about customers helps companies to identify their customers' needs and expectations and consequently a more accurate definition of value and waste. It will facilitate the prioritization process for companies to identify areas that need designers' attention. The second variable, variety of sources to attain information about customers, helps companies to avoid biased information and enable them to gather more accurate and reliable information. For the third variable, quality of communication between the design

and marketing teams, any problem in the flow of information between the design team and marketing team might avert the designers into a completely improper direction. The measurements factors regarding information about customers and their corresponding survey questions are presented in Table 1 to Table 3.

Table 1 The Quantity and Quality of Information about Customers Measurements and Questions

1. The Quantity and Quality of Information about Customers

**Measurements:**

The quality of information about users
The quantity of information about users.
Reliability and accuracy of definition of value and waste based on customers' information.

**Survey Questions:**

1.1) Please rank the following design approaches based on your company's design strategies and preferences (1- Being most preferable, 3- Being least preferable).

☐ Offering the final product at a fair price
☐ Meeting customers' requirements/needs
☐ Decreasing the design and development time

For the following questions, Please indicate to what extent you agree or disagree with each of the statements:

1.2) Your company knows who the users of the product(s) are.
1.3) Your company knows how the customers use the designed product(s) in their process(es).
1.4) Your company's estimate of fair price is close to customers' expectations of fair price. (Fair price: A reasonable correlation between the provided features and the requested amount paid by customers)
1.5) Competitors' products are analyzed within defined periods of time by your company.
1.6) The design team members define value and waste within the system based on your company's organization viewpoint. (Organization viewpoint: Characteristics and features that are considered as "value" or "waste" by the organization)
1.7) The design team members define value and waste within the system based on the customers' viewpoints. (Customers viewpoint: Characteristics and features that are considered as "value" or "waste" by customers)

Question 1.1 is used to identify respondents' design strategy priority. The results from this question will be compared with respondents' answers to the rest of the survey questions to see if the considered strategy was applied correctly or not. For instance, a respondent that chose "Meeting customers' requirements/need" as the first priority during the design process but his/her agreement level with the statement in question 1.2 is low, it will indicate a contradiction between their priority and their current situation and eventually it can show us their product design process needs significant improvement to become lean.

For questions 1.2 to 1.7, higher agreement score indicate higher level of lean product design process.

Table 2 Variability of Sources to Attain Information about Customers Measurements and Questions

| 2. Variability of Sources to Attain Information about Customers |
|---|
| **Measurements:**<br><br>The appropriateness and adequateness of information gathering sources about users<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>2.1) A specific product can satisfy all different types of customers with different requirements.<br>2.2) Your company frequently selects a sample of customers to ask them about their needs and wants.<br>2.3) Your design team directly interviews/surveys the customers on a frequent basis about their experiences of your products.<br>2.4) Your company assigns focus groups to observe customers' experiences of using or misusing your products for extended periods of time.<br>2.5) Your company offers benefits to customers that use your product(s) in an innovative manner that were not identified by you originally.<br>2.6) Your company involves customers in the design process as developers. |

For questions 2.1 to 2.6, higher agreement score indicate higher level of lean product design process except for question 2.1, which asked the opposite way to check

the reliability of respondents and the higher disagreement level score indicate higher level of lean product design process.

Table 3 Quality of Communication between Design and Marketing Teams Measurements and Questions

| 3. Quality of Communication between Design and Marketing Teams (about customers): |
|---|
| **Measurements:**<br><br>The quality of communication between the marketing and design teams<br>The quality of information flow between the design and the marketing teams through frequent meetings.<br>The quality of information flow between the design and the marketing teams through the use of quantitative information.<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>3.1) How frequently have you held meetings of the Design team and the Marketing team in your company?<br>• Every week<br>• Every month<br>• Every three month<br>• Once a year<br>• Never<br>3.2) If there were meetings of the Design and Marketing teams, how long did they usually last?<br>• 0-30 minutes<br>• 30-60 minutes<br>• 60-90 minutes<br>• 90 minutes or more<br>3.3) The information presented by the design and marketing teams during such meetings was more ***Quantitative*** (using numbers) instead of ***Qualitative*** (verbal explanation)**.** |

For question 3.1, the more frequent meetings will result in higher level of lean product design. For question 3.2, since the frequent meetings need to be concise the shorter the duration is, the leaner the product design process will be. For question 3.3, higher agreement score indicate higher level of lean product design process.

### 4.3.2 Measurements Corresponding to the Variables of Cost and Time

To investigate the impact of consumed cost and time on leanness of the design process of a company, measurements for the variables related to cost and time are developed. The main variables of cost and time for lean product design include variability of outcomes, complexity of the design process, defects, technology to use, the percentage of design reuse, the percentage of design change after manufacturing, effective communication, DFM ensuring compatibility, and standardized parts and materials. All of the measurements regarding variables of cost and time and their corresponding questions are presented in Table 4 to Table 11.

Table 4 Variability of Outcomes/Standardized Design Process Measurements and Questions

| 4. Variability of Outcomes/Standardized Design Process |
|---|
| **Measurements:**<br><br>The reduction of outcome variability<br>The use of standardized operating procedures and regulations in the design process.<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>4.1) Your company tries to define standardized and structured design process.<br>4.2) New standard operating procedures are frequently introduced into the design process. |

For questions 4.1 and 4.2, higher agreement score indicate higher level of lean product design process.

Table 5 Complexity in the Design Process / Simplification Measurements and Questions

| 5. Complexity in the Design Process / Simplification |
|---|
| **Measurements:**<br><br>The identification and removal of redundant steps<br>Design simplification<br>Level of allowable change to design processes. |

**Survey Questions:**
For the following questions, Please indicate to what extent you agree or disagree with each of the statements:

5.1) Your product design process is frequently reviewed by experts to remove redundant steps.
5.2) In new product designs, your design team simplifies designs as much as possible by emphasizing commonality.
5.3) Your company discourages dramatic round-to-round changes to product designs.

For questions 5.1 to 5.3, higher agreement score indicate higher level of lean product design process.

Table 6 Defects Measurements and Questions

| 6. Defects |
|---|
| **Measurements:**<br><br>The use of "Zero Defect" approach during the design process.<br>The number of design defects<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>6.1) Any numbers of defects are unacceptable and everyone on the design team tries to complete tasks correctly the first time.<br>6.2) All design team members try to accomplish their tasks as soon as possible and then all the tasks get reviewed for errors. |

For questions 6.1 and 6.2, higher agreement score indicate higher level of lean product design process.

Table 7 Technology to Use Measurements and Questions

| 7. Technology to Use |
|---|
| **Measurements:**<br><br>Designers' skills in work with high-tech instruments and software.<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>7.1) The designers have the required skills to work with high-tech instruments and software. |

| |
|---|
| 7.2) The designers stay up to date with the latest technologies used in design. |

For questions 7.1 and 7.2, higher agreement score indicate higher level of lean product design process.

Table 8 The Percentage of Design Reuse Measurements and questions

| 8. The Percentage of Design Reuse |
|---|
| **Measurements:**<br><br>The reuse of an existing platform from prior designs<br>The reuse of modules from prior designs<br>The reuse of components from other designs<br>The reuse of requirements from prior designs<br>The reuse of design testing from prior designs<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>8.1) Your design team extends an existing platform from the prior designs to design new product(s).<br>8.2) Your design team reuses modules from the prior designs to design new product(s).<br>8.3) Your design team tries to reuse components from the other designs to design new product(s).<br>8.4) Your design team analyzes and manages design requirements at a suitable abstraction level so that they can be reused in a new system.<br>8.5) Your design team reuses tests (between iterations?) from the prior designs or reuse common test patterns to test their designed product(s). |

For questions 8.1 to 8.5, higher agreement score indicate higher level of lean product design process.

Table 9 Design Change after Manufacturing Measurements and Questions

| 9. Design Change after Manufacturing |
|---|
| **Measurements:**<br><br>M17: Level of design change after manufacturing and before product release<br><br>**Survey Questions:**<br>For the following question, Please indicate to what extent you agree or disagree with the statement:<br><br>9.1) In your company, design change after manufacturing takes place frequently. |

For question 9.1, higher agreement score indicate higher level of lean product design process.

Table 10 Effective Communication Measurements and Questions

| 10. Effective Communication |
| --- |
| **Measurements:**<br><br>Clarity of the organization's vision and strategies<br>The use of effective channels to facilitate communication between departments<br>The use of electronic tools to share any change, progression, or problem within one team with all the other teams<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>10.1) The vision and strategies of your company are clearly communicated to the design team members.<br>10.2) Effective channels (i.e. electronic grapevines, frequent meetings, etc.) are available for design team members to directly communicate with members in other departments.<br>10.3) If multiple design teams are working on the same product, any progression, change, or problem within one team is shared with all the other teams. |

For questions 10.1 to 10.3, higher agreement score indicate higher level of lean product design process.

Table 11 DFM Ensuring Compatibility Measurements and Questions

| 11. DFM Ensuring Compatibility |
| --- |
| **Measurements:**<br><br>The compatibility of new design with current manufacturing process<br>The degree of part integration<br>The degree of part standardization<br>The degree of material standardization<br>The use of standardized parts and materials<br><br>**Survey Questions:**<br>For the following questions, Please indicate to what extent you agree or disagree with each of the statements:<br><br>11.1) In your new product designs, compatibility with current manufacturing processes is emphasized. |

| | |
|---|---|
| 11.2) | In your new product designs, the use of standardized parts is emphasized. |
| 11.3) | New parts are frequently standardized in your firm. |
| 11.4) | In your new product designs, design teams try to minimize the use of new materials (existing or emerging materials that have not been used in the specific type of products under design). |

For questions 11.1 to 11.4, higher agreement score indicate higher level of lean product design process.

The measurements corresponding to value analysis can be classified into "matching product design with customer needs and expectations" and "ranking product attributes based on different approaches" [18]. Design team members need to add features to the product that match the requirements and needs of the customer. This can be measured by evaluating the level of organization's emphasize on meeting customer demands and requirements and also assessing the level of features that defined by the customers. Consequently, it highly depends on the level appropriate information that organizations have about their customers.

Product attributes can be classified into different categories including: attributes that meet the requirements of the customer, attributes based on the internal views of the organization, and attributes that are a response to the actions of its competitors[18]. In a lean organization the attributes that meet the requirements of the mainstream customers will have the first priority. The measurements and corresponding survey questions in regard to value analysis are presented in Table 12.

Table 12 Value Analysis Measurements and Questions

| 12. Value analysis |
|---|
| **Measurements:**<br><br>The degree of design specification based on customer requirements<br>The degree of product feature prioritization based on customer inputs<br>The degree of product attributes based on internal beliefs.<br>The degree of product attributes based on a response to competitors' actions. |

**Survey Questions:**

12.1) When deciding on what attributes to be included in a product design, primary weight is given to (1- highest priority; 3- lowest priority):

☐ Attributes that meet the current customers' requirements
☐ Attributes that enhance technological superiority based on internal beliefs
☐ Attributes that are a result of response to competitors' actions

For the following questions, Please indicate to what extent you agree or disagree with each of the statements:

12.2) Your company discourages designs of products/product features that current customers do not require.
12.3) Product design specifications can all be traced back to customer requirements.
12.4) Your company allocates a high percentage of resources to improve the product along the dimensions of performance that the mainstream customers require.
12.5) Your company allocates a high percentage of resources to design product attributes that are not valued by the mainstream customers.

Question 12.1 is used to identify respondents' priority in considering attributes in product design process and then comparing results with their answers to the rest of questions. For questions 12.2 to 12.5, higher agreement score indicate higher level of lean product design process.

The results of the designed survey help companies to evaluate their design process and also enable them to identify their weaknesses. In other words, interpretation of designers' responses provides them with useful information that let them identify the steps or areas that need their focus to make their design process leaner.

CHAPTER 5

# CONCLUSION

In this thesis, a lean product design measurement matrix is developed based on a comprehensive review of literature in lean product design. Different measurable factors that provide organizations a consensus, comprehensive, and more detailed definition of lean product design and also enable organizations to evaluate their product design process performance were identified and discussed. Also, the importance of attaining enough information from reliable sources was discussed. Even though all the lean thinking practices have the same core concept, there are widespread differences in the execution of each of them. Consequently, I tried to identify the different steps and tasks in a new product development process, specifically the design process. Then with sufficient knowledge about the process, a lean product design measurement matrix was presented.

One of the limitations of this study is that the developed measurement matrix has not been tested by practicing design engineers and lean management teams. Future study includes in-depth investigations to test the validity and accuracy of the developed matrix in this study. The effectiveness of the suggested matrix will be examined in different industries. A nationwide survey can be conducted to ask design engineers if the suggested solutions are useful or not. Based on the new information, supplementary suggestions to make the current results more effective and applicable can be developed.

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# Appendix A:

## DESIGNED SURVEY QUESTIONS CORRESPONDING TO MEASURMENT FACTORS

Please rank the following design approaches based on your company's design strategies and preferences (1- Being mot preferable, 3- Being least preferable).

| | |
|---|---|
| Offering the final product at a fair price | 1 |
| Meeting customers' requirements/needs | 2 |
| decreasing the design and development time | 3 |

Please indicate to what extent you agree or disagree with the statement.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Your company knows who the users of the product(s) are. | ○ | ○ | ○ | ○ | ○ |
| Your company knows how the customers use the designed product(s) in their process(es). | ○ | ○ | ○ | ○ | ○ |
| Your company's estimate of fair price is close to customers' expectations of fair price. (Fair price: A reasonable correlation between the provided features and the requested amount paid by customers) | ○ | ○ | ○ | ○ | ○ |
| Competitors' products are analyzed within defined periods of time by your company. | ○ | ○ | ○ | ○ | ○ |
| The design team members define value and waste within the system based on your company's organization viewpoint. (Organization viewpoint: Characteristics and features that are considered as "value" or "waste" by the organization) | ○ | ○ | ○ | ○ | ○ |
| The design team members define value and waste within the system based on the customers' viewpoints. (Customers viewpoint: Characteristics and features that are considered as "value" or "waste" by customers) | ○ | ○ | ○ | ○ | ○ |

Figure 6 Survey Questions Implemented in Qualtrics

Please indicate to what extent you agree or disagree with the statement.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| A specific product cannot satisfy all different types of customers. | ○ | ○ | ○ | ○ | ○ |
| Your company frequently selects a sample of customers to ask them about their needs and wants. | ○ | ○ | ○ | ○ | ○ |
| Your design team directly interviews/surveys the customers on a frequent basis about their experiences of your products. | ○ | ○ | ○ | ○ | ○ |
| Your company assigns focus groups to observe customers' experiences of using or misusing your products for extended periods of time. | ○ | ○ | ○ | ○ | ○ |
| Your company offers benefits to customers that use your product(s) in an innovative manner that were not identified by you originally. | ○ | ○ | ○ | ○ | ○ |
| Your company involves customers in the design process as developer. | ○ | ○ | ○ | ○ | ○ |

Figure 7 Survey Questions Implemented in Qualtrics

How frequently have you held meetings of the Design team and the Marketing team in your company?

- Every week
- every month
- Every three months
- Once a year
- Never

If there were meetings of the Design and Marketing teams, how long did they usually last?

- 0-30 minutes
- 30-60 minutes
- 60-90 minutes
- 90 minutes or more

Figure 8 Survey Questions Implemented in Qualtrics

Please indicate to what extent you agree or disagree with the statement.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| The information presented by the design and marketing teams during such meetings was more Quantitative (using numbers) instead of Qualitative (verbal explanation). | | | | | |

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Your company tries to define standardized and structured design process. | | | | | |
| New standard operating procedures are frequently introduced into the design process. | | | | | |

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Your product design process is frequently reviewed by experts to remove redundant steps. | | | | | |
| In new product designs, your design team simplifies designs as much as possible by emphasizing commonality. | | | | | |
| Your company discourages dramatic round-to-round changes to product designs. | | | | | |

Figure 9 Survey Questions Implemented in Qualtrics

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Any numbers of defects are unacceptable and everyone on the design team tries to complete tasks correctly the first time. | ○ | ○ | ○ | ○ | ○ |
| All design team members try to accomplish their tasks as soon as possible and then all the tasks get reviewed for errors. | ○ | ○ | ○ | ○ | ○ |

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| The designers have the required skills to work with high-tech instruments and software. | ○ | ○ | ○ | ○ | ○ |
| The designers stay up to date with the latest technologies used in design. | ○ | ○ | ○ | ○ | ○ |

Figure 10 Survey Questions Implemented in Qualtrics

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Your design team extends an existing platform from the prior designs to design new product(s). | ○ | ○ | ○ | ○ | ○ |
| Your design team reuses modules from the prior designs to design new product(s). | ○ | ○ | ○ | ○ | ○ |
| Your design team tries to reuse components from the other designs to design new product(s). | ○ | ○ | ○ | ○ | ○ |
| Your design team analyzes and manages design requirements at a suitable abstraction level so that they can be reused in a new system. | ○ | ○ | ○ | ○ | ○ |
| Your design team reuses tests (between iterations?) from the prior designs or reuse common test patterns to test their designed product(s). | ○ | ○ | ○ | ○ | ○ |

Please indicate to what extent you agree or disagree with the statement.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| In your company, design change after manufacturing takes place on a frequent base. | ○ | ○ | ○ | ○ | ○ |

Figure 11 Survey Questions Implemented in Qualtrics

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| The vision and strategies of your company are clearly communicated to the design team members. | | | | | |
| Effective channels (i.e. electronic grapevines, frequent meetings, etc.) are available for design team members to directly communicate with members in other departments. | | | | | |
| If multiple design teams are working on the same product, any progression, change, or problem within one team is shared with all the other teams. | | | | | |

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| In your new product designs, compatibility with current manufacturing processes is emphasized. | | | | | |
| Designs of your products are compatible with the existing manufacturing process at your company (no new equipment or technology is needed to manufacture the new designs). | | | | | |

Figure 12 Survey Questions Implemented in Qualtrics

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| In your new product designs, the use of standardized parts is emphasized. | | | | | |
| New parts are frequently standardized in your firm. | | | | | |
| In your new product designs, design teams try to minimize the use of new materials (existing or emerging materials that have not been used in the specific type of products under design). | | | | | |

Please indicate to what extent you agree or disagree with each of the statements.

| | Strongly Agree | Agree | Neutral | Disagree | Strongly Disagree |
|---|---|---|---|---|---|
| Your company discourages designs of products/product features that current customers do not require. | | | | | |
| Product design specifications can all be traced back to customer requirements. | | | | | |
| Your company allocates a high percentage of resources to improve the product along the dimensions of performance that the mainstream customers require. | | | | | |
| Your company allocates a high percentage of resources to design product attributes that are not valued by the mainstream customers. | | | | | |

Figure 13 Survey Questions Implemented in Qualtrics

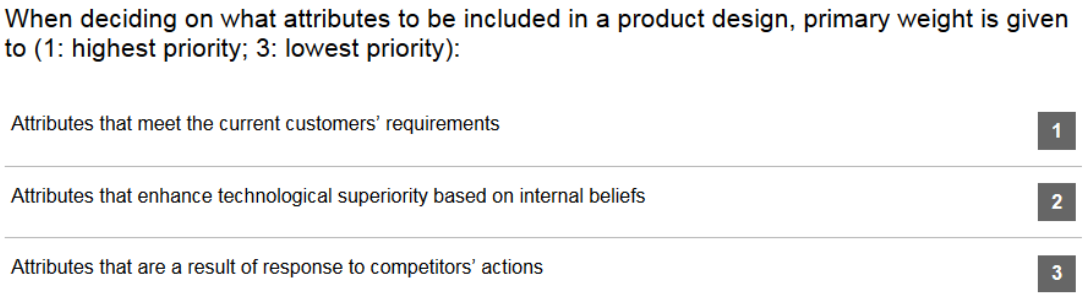


Figure 14 Survey Questions Implemented in Qualtrics