Development of a Life Cycle Assessment Benefit Assessment for the Benefit Evaluation of Products and Processes

by

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ABSTRACT

As the world advances in age, new technologies emerge to provide the people new products and services to satisfy their needs. But at what cost? These new products and services provide benefits but at the same time generate unintended outcomes or consequences such as resource depletion and waste generation. There are different methodologies that provide the capability of evaluating these consequences or impacts. On the other hand there is a need to determine or evaluate how a product or service meets the overall customer needs. Presently, there is a need for a benefit assessment that can evaluate the benefits of products/services based on how well the customer needs are satisfied. This research is focused on the creation of a benefit assessment methodology to evaluate products/services. It was then applied to a product and a service to see the results and evaluate them if it was a valid assessment tool. This methodology, in combination with existing ones such as Life Cycle Assessment, could be a great tool to evaluate products/services completely in a whole new way.

RESUMEN

Mientras el mundo avanza en edad, nuevas tecnologías son desarrolladas para crear nuevos servicios y productos. Estos productos y servicios, al ser nuevos, crean un impacto tanto en el humano como en el medio ambiente. Es necesario el uso de herramientas como la Evaluación del Ciclo de Vida para evaluar estos productos/servicios y ver su impacto. Pero para hacer una evaluación completa, hay que hacerla en todos sus aspectos. Desarrollando una metodología de evaluación de beneficios, se puede añadir una nueva dimensión a esta evaluación. Esta se desarrollo y luego se aplico a un producto y a un servicio. Se analizaron los resultados obtenidos y se llego a conclusiones. Esta puede ser una adición útil para poder hacer evaluaciones de productos y servicios más completos.

To you…

believing in me always,

made this possible…

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1 INTRODUCTION

1.1 Overview

Today's world provides technological advances in the form of a great variety of products and services to the people due to their needs. The needs of the people maintain industries in continuous search for new advances that will allow for the development of new products and services. A manufacturing company or service provider company must keep track of these needs and develop new technologies that can provide solutions for their customers. Industries that do not keep current with customer needs and market trends will not be supported by the market and could eventually fail.

A benefit can be referred to the features a customer desires or needs from a product or service. Since there are many people with different needs or desires, there is a great variety of benefits that can be considered of certain product or service. According to a online dictionary, a benefit is an advantage gained from something.[1]

People looking for a product or a service search for certain benefits that can satisfy their needs. This is why companies seek to develop services and manufacture products to satisfy the demands of the marketplace. These demands might be based on customer's needs such as the desire to have something to feel comfortable in life. Many times, customers acquire products or services that partially fulfill their needs. The benefits of the product or service are not properly aligned with the needs or desires of the customer. The figure 1.1 portrays this situation; as seen there is not perfect line up between them.

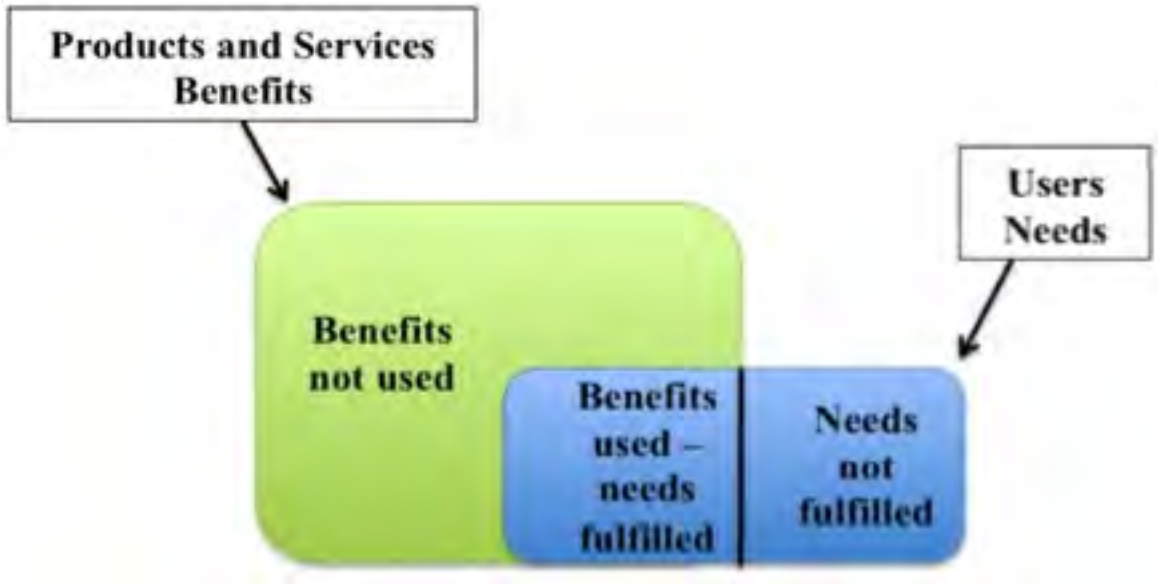

Figure 1.1 Alignment between the benefits and the customer's needs

In order to create these products/services, companies invest millions of dollars to develop the necessary technologies to produce them, taking into account several things. Figure 1.2 shows how a product can be viewed as a complete functional system composed of many subsystems. These subsystems are made up the different parts that develop the product. The parts are made of materials, which these materials are made up of raw materials. There is a need to create a process to be able to create the product. Raw materials go through a process to produce materials. Materials pass through other processes to produce the parts needed to create the different subsystems. Then, these subsystems are assembled to create the final product.[2]

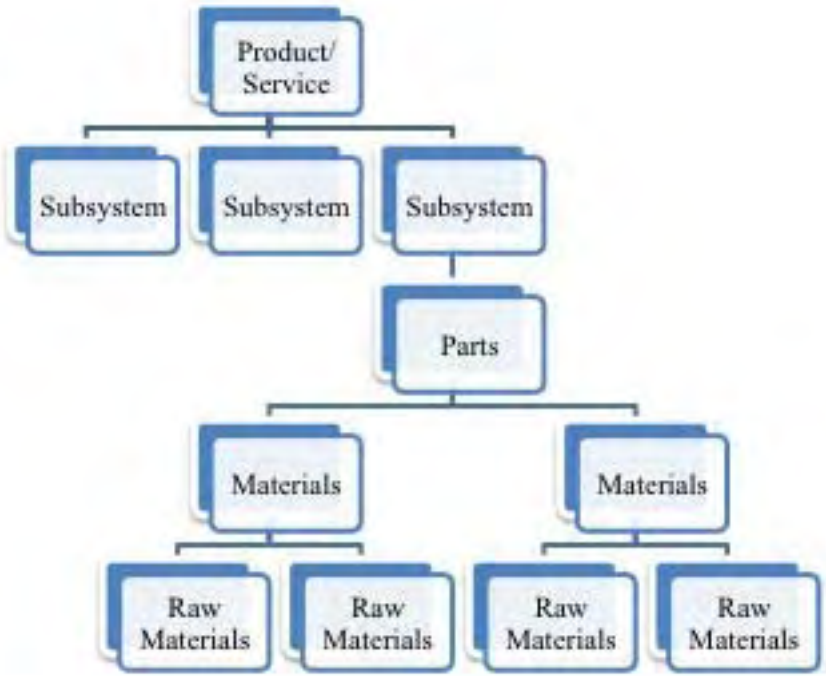

Figure 1.2 Diagram of product cycle for the manufacturing of a product

1.2 Current LCA Methodology

Current and emerging technologies generate diverse environmental impacts on the planet and the people living in it. Presently, more companies are becoming concerned with the environmental problems that arise by the products and services they provide. As part of these environmental concerns, some companies have started to monitor and evaluate their daily activities in order to try to control, diminish or even eliminate the environmental impact or their operations[3]. These companies quantify inputs and outputs of their manufacturing procedures such as raw material and energy consumption at their facilities and operations; and then assess the environmental impacts of these inputs and outputs. This systematic approach is the basis of Life Cycle Assessment (LCA). This environmental assessment technique evaluates certain activity or procedure from the time in which raw materials are obtained to the time when the product is decommissioned. It is a very complicated assessment that includes all the steps taken to develop the product, its uses and later decommissioning it. The assessment includes effects

and consequences in the three main environmental systems such as air, water, and soil. The figure below illustrates the life cycle assessment schematic with all its stages.[3]

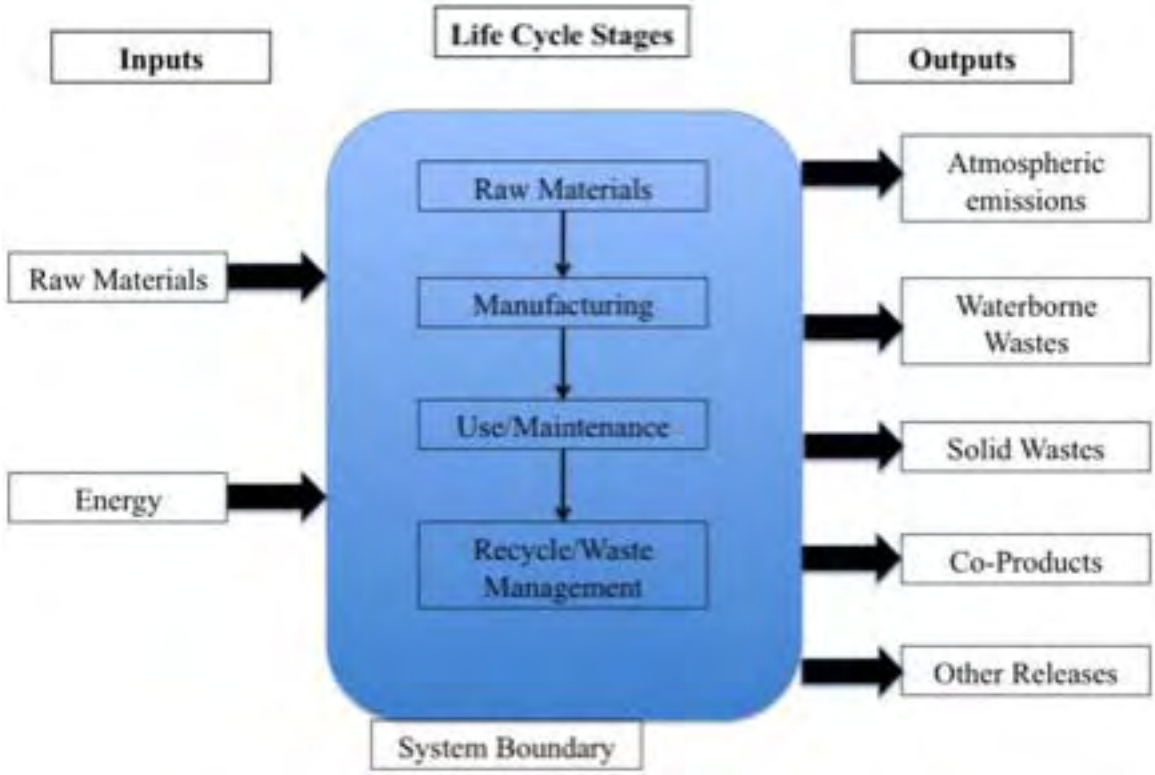

Figure 1.3 Life Cycle Assessment Stages

The Society of Environmental Toxicology and Chemistry (SETAC) defined LCA as a step approach[3]. It is composed of three major components:

- Inventory
- Impact Assessment
- Improvement Assessment

Before starting an LCA, the analyst must define the goal and the scope of the assessment. This is a very important step because it is what describes the purpose of the assessment. The inventory is the step in which the energy used, the raw materials consumed, the air emissions released, the waterborne waste created, the solid waste generated, and other releases are quantified throughout the life of the product or service. Impact assessment is the component of the analysis in which

the environmental hurdles identified in the inventory are characterized and assessed. This assessment should be based on the environment and the human health impact. The improvement assessment is the component in which the results of the impact assessment are evaluated to come up with possible solutions trying to avoid the environmental impacts or trying to reduce them as time passes and the product or service evolves.[3, 4]. All these concepts will be explained in detail in the next chapter.[5]

LCA is a great tool to evaluate a process, a product, or a service, but it has some limitations. First of all, using LCA may prove to be very expensive.[3, 6] This is because the nature of the assessment covers the whole process of producing a product or creating a service until end of life. Because of this, some companies may decide not to complete the whole assessment, focusing mostly on just the inventory step and, based on that, make their assumptions and improvements. Another important limitation is the fact that LCA only deals with the impact of certain product or service. But, what about how can the products benefit the customer or user? The benefits in LCA are included implicitly in the methodology. They are stated when a functional unit is defined. For example in the transportation industry, a functional unit could be defined as passenger/miles. In a car, a maximum of 5 passengers can be transported over a certain number of miles. In a bus, 30 passengers can be transported over the same amount of miles. Viewing this, the bus transportation provides a better benefit of transporting passengers over a certain amount of miles. But, what about the benefit of comfort? This can be seen as another benefit in the transportation industry. The previous defined functional unit does not take into consideration this benefit. Then, the functional unit must be redefined or another functional unit must be created to include this benefit. Different values of benefit can be obtained this way but not a benefit that contains them all. LCA does not have a

structured method of obtaining the benefits of a product or service. Comparing what the product or service can offer with the impacts produced will be very useful to the companies to make them better with a lesser impact to the environment and the users.

1.3 Research Scope and Objectives

Creating a Benefit Component to incorporate it to the LCA, a Benefit-to-Impact ratio can be obtained. The ratio would be a number that changes as the product or service is improved in both benefit and impact components giving an idea of how it relates to the necessities. The figure below, shows how the Benefit Component is added to the process of the LCA methodology changing the original assessment basis.[2]

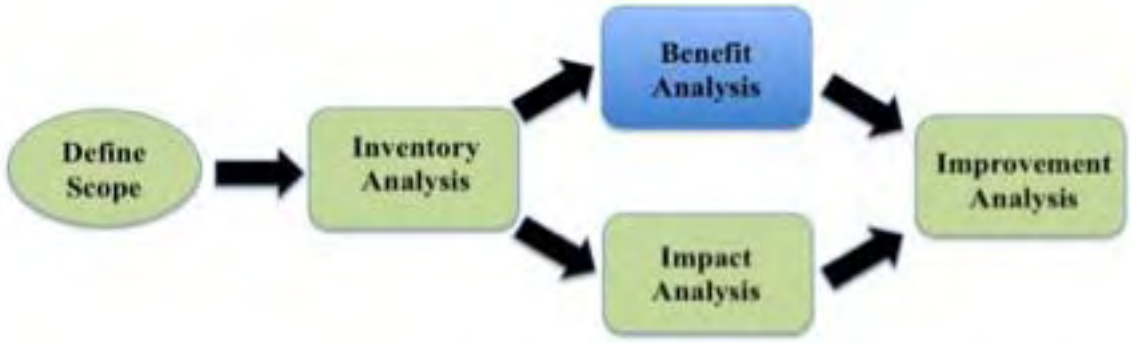

Figure 1.4 Proposed LCA methodology including a Benefit Component

Basically, the scope of this research relies in the creation of a Benefit Component for the LCA Methodology. This benefit component would be based on what the customer would want or desire of certain product or service. It will be worked using the House of Quality tool of the Quality Function Deployment (QFD). In later chapters, these tools will be explained in detail. The main objectives of this research include:

- Research Quality Function Deployment and its tools.
- Create the Benefit Component methodology based on those tools.

- Select a product and apply the methodology to it.
- Select a service and apply the methodology to it.
- Improve the methodology after completing both the service and product.

1.4 Summary

As the world changes, technology evolves. With these technological advances, new products and services are created for the benefit of mankind. But, as they evolve, the environment and the people are affected because of these changes. There are several tools that help assess all the changes affecting the world. Life Cycle Assessment is one of these tools that help assess the impact and helps in ways to improve it. To be able to create a better product or service, the benefit part provided to the needs must be taken into account. By adding another component to the LCA methodology helps us assess what is the benefit a product or service might have. This research focuses in the creation of the benefit component methodology to include in the LCA and its application to a product or service.

2 LITERATURE REVIEW

2.1 ISO 14040 family

The ISO 14040 family is the set of standards created by the ISO Technical Committee 207. It is mainly composed of four standards and a report created by experts in the field of Life Cycle Assessment. ISO 14040 is an introduction of what is Life Cycle Assessment and what is to be achieved by it. ISO 14041 talks about the standards needed when setting the Goal and the scope of the study and ways to create the Inventory. ISO 14042 talks about the impact assessment and current practices. Finally ISO 14043 talks about the Improvement Analysis and the different ways it can be performed. These are generally accepted to provide a consensus for a LCA framework.[7, 8]

2.2 Current LCA Methodology

Life Cycle Assessment (LCA) helps in the identification process of environmental impacts. In order to translate those impact results into a quantifiable value, the investigator in charge uses his/hers judgment and applies it to a series of phases. There are different ways to apply the LCA methodology. Each investigator modifies accordingly what they want to study. As mentioned before, Life Cycle Assessment methodology is composed of four phases. Each phase defines an important step that needs to be taken in order to complete the methodology.[7, 9]

2.2.1 Phase 1: Goal Definition and Scope

The first phase is Goal Definition and Scope. This phase explains why the study is being done and to what extent. Three important questions must be answered in this phase:

- What type of information is going to be used?
- What accuracy is needed in the results?
- How results are going to be analyzed, interpreted, and presented?

The Goal Definition and Scope phase is very important. This phase details important aspects of time and resources needed for the determination of environmental impacts of any product, service, or process. Any decision taken in this phase will affect the whole study. With this said, it is very important to complete this phase carefully with all the aspects pertaining to it.[7, 9]

There are six determinations that need to be made in this phase [9]:

1. Determine Study's Goal
2. Determine the type of information needed
3. Determine how specific the study should be
4. Determine data organization and presentation
5. Determine the Study's Scope
6. Determine general rules while performing the methodology

2.2.1.1 Determine the Study's Goal

The goals of a study depend on the type of study that is to be conducted. Defining the goals at the beginning is important since the LCA is a tool that can be used for the identification and quantification of the environmental impacts of a product, process or service. The main goal would be the selection of the product, service, or process that has the least consequence to the people and to the environment when compared to others. In other words, how can the environmental performance of the product/service/process could be enhanced without changing it completely [4]. When determining the goal of the study, several evaluations might be

important to include them. Some of these are [9]:

- Support broad evaluation of the environment
- Define basic information of current practices of a product, service, or process
- Provide data of each process step
- Determine gaps in the process
- Support current public policies
- Provide information for decision-making.

2.2.1.2 Determine the type of information needed

It is very important to provide the correct information for what is wanted. LCA will provide the necessary information to help answer important questions. To answer these questions, selection of the necessary type of data needed is crucial.[7, 9]

Data can be quantitative or qualitative. Quantitative data has more advantages because it is easier to acquire and to interpret. Qualitative data can also be as valuable as quantitative but using it can be controversial. People can have different judgments towards something and that could interfere with the results.[4]

2.2.1.3 Determine how specific the study should be

For any study, decisions of how specific it needs to be must be taken. Depending on the application or the use of the data, the level of specificity will be determined. This level should be described in detail for others to understand it. This is one important step before beginning the study.[7, 9]

2.2.1.4 Determine data organization and presentation

In LCA practice, data is organized in terms of a functional unit. The selection of the functional unit is important to portray the accuracy of the study. This functional unit will

describe the product, process, or service accordingly [9]. It is a description of its performance according to various aspects [7].

2.2.1.5 Determine the Study's Scope

Determination of the scope is needed to see to what extent the study should be taken. Since LCA is time and resource consuming, the determination of the scope will help settle the amount of time and resources needed to complete the study and give valid results. Several questions that help determine this are the following [4, 9]:

- Who is performing the study?
- What resources are available?
- What is the most limited scope of the study that could provide accurate aspects of the study?
- Does life cycle of the product/service/process needs to be completely studied?
- Are there any other products/service/process similar to the one studied and are there any differences?
- What is the basic use of the product/service/process?

The answer to these questions will help determine the boundaries of the study. This will give the necessary directions without affecting the primary goal of the study and the interpretation of the results. Boundaries will also help regulate time and resources needed to complete the study.[7, 9] The extent of the analysis should relate to the degrees of freedom present when making important decisions among the various options.[4]

2.2.1.6 Determine general rules while performing the methodology

Before beginning the next phase of the methodology, assumptions must be made and documented. If they are not included with the final results of the study, the study might be

inconclusive and might be interpreted incorrectly. Quality confidence is needed throughout the entire process of the methodology. Following correct procedures will produce confidence in the results. Another general rule that needs to be followed is to define how reports will be presented and what elements are crucial when reporting final results.[7, 9]

2.2.2 Phase 2: Life Cycle Inventory (LCI)

The next phase in the LCA methodology is the Life Cycle Inventory (LCI). In LCA methodology, LCI is a process where raw materials and energy used, atmospheric emissions, waterborne emissions, solid wastes, and other wastes are quantified for the life cycle of product/process/service. All data is gathered and arranged in a uniform manner. This phase has many uses. The inventory could be used as a tool of policy-making by the government. It can also help an organization by comparing products/services/processes and consider their environmental impacts.[9, 10]

The LCI consists primarily of four steps [9]:

1. Establishment of flow diagrams of the different processes
2. Establishment of a plan for data collection
3. Collection of data
4. Assessment and report results

2.2.2.1 Establishment of flow diagrams of the different processes

The first step is to design a flow diagram that describes the inputs and outputs of each process. The boundaries defined in the goal and scope of the study are used to construct the flow chart. Flow charts will present information accurately in a step-by-step form. Data gathered in the inventory should be associated with a measure of quality. This is important when using human judgment in later phases.[9]

2.2.2.2 Establishment of a plan for data collection

A data collection plan makes sure that the quality and preciseness of the data being collected meets the requirements established in the phase of Goal definition and Scope. This plan must be validated so it meets the objectives defined in the previous phase. Important components in this step include [9]:

1. Establishment of data quality goals
2. Data sources identification
3. Data quality indicators identification
4. Development of a collection worksheet and checklist

2.2.2.3 Collection of data

This step implies the use of research, visits and direct contact with experts to produce large amounts of data. There are different ways to create the inventory. Researching the different ways is important so the organization can make the best selection of the process to collect the data.[9]

2.2.2.4 Assessment and report results

The last step of the LCI is the assessment and report of the results. When making the reports of the LCI, the methodology used to gather the data should be explained in detail with all of its assumptions. This will provide a clear process of what was done and no doubts can be found analyzing the report. The report basically will consists of all the amounts of inputs and outputs used when creating a product/service/process.[9]

2.2.3 Phase 3: Life Cycle Impact Assessment (LCIA)

The next phase in the LCA methodology is Life Cycle Impact Assessment (LCIA). In this phase, all the inputs and outputs identified in the LCI are evaluated for their possible

environment and human health impact. This assessment should take into consideration all the ecological and human health effects caused by certain product/process/service. LCIA is done because it can determine which of the releases or resources in the process have a greater impact. It is a more profound analysis than LCI.[9, 11, 12]

In order to complete the LCIA, the following steps have to be made [1,4]:

1. Selecting and explaining Impact Categories
2. Categorization
3. Characterization
4. Normalization
5. Grouping
6. Valuation
7. Assessment and report LCIA results

2.2.3.1 Selecting and explaining Impact Categories

In this step, impact categories are chosen for the study. There exists three main categories [9, 11, 13]:

- Human health
- Ecological health
- Resource depletion

It is important to understand that impact is the consequence caused by the inputs and outputs on a human, animal, and the environment. These categories are later subdivided in more categories, depending on the scope of the study.[9, 11]

2.2.3.2 Categorization

The main objective of this step is to organize the LCI into its corresponding category.

Some LCI results can be categorized in more than one category. Special procedures must be taken to divide it correctly.[9, 11, 14]

2.2.3.3 Characterization

In this step, characterization factors are used to modify and combine LCI results into indicators of human and ecological impacts. Equations are used to multiply the inventory data by its characterization factor to generate impact indicators. Many characterization factors are already created. If not, then the indicator must be created and validated.[9, 11, 12]

2.2.3.4 Normalization

This step uses impact indicator data to express it in a way that could be compared to other impact categories. There are various ways to normalize the data. The way it is going to be normalized would be selected during the Goal Definition and Scope phase.[9, 11]

2.2.3.5 Grouping

Data is sorted and grouped depending on their values and characteristics. This is done to understand better the data and make a better judgment when categorizing it.[9, 11]

2.2.3.6 Valuation

The valuation step in an LCIA consists of giving values to each category to include the importance of each category compared to others. It is very important to explain these weighting factors clearly because there doesn't exist an specific method to value them.[9, 11]

2.2.3.7 Assessment and report LCIA results

The final step in the LCIA is to calculate the value for each category and final conclusions are done based on the assumptions made in the first phase. Values must be accurate to make the best decisions in the next phase of the LCA methodology.[9, 11]

2.2.4 Phase 4: Life Cycle Improvement Assessment

The final phase of the LCA methodology is LCA Improvement Assessment. It basically consists of generating conclusions and recommendations based form the other phases and rating them according to their environmental and non-environmental status [4]. Interpreting results is not as easy as it may seem. All the data has to be viewed in its own context to make the better choice from it.

To interpret the results, the following steps need to be followed [9, 15]:

1. Identification of important issues in LCI and LCIA
2. Assessment including completeness, sensitivity, and consistency
3. Conclusions, recommendations, and report

2.2.4.1 Identification of important issues in LCI and LCIA

This step involves the review of the three previous phases to select important issues relevant to each phase. By reviewing the data from previous phases, it can be determined if the goal and the scope of the study was accomplished.[9, 15]

To determine if an issue has some degree of importance, several methods could be used. The contribution analysis method views the contribution of each stage compared to the total result obtained at the end of the LCIA. The dominance analysis method uses statistical tools to identify important contributors. The anomaly evaluation method uses previous experiences and recent observations to search for anomalies in the study.[9, 15]

2.2.4.2 Assessment including completeness, sensitivity, and consistency

This step indicates the confidence and reliability of the results of the previous phases. Several tasks need to be completed to accomplish this step. A completeness check must be done to the entire study to see if nothing of relevant importance is missing. A sensitivity check is

done to evaluate the sensitivity of the data that influences the results. A consistency check is also done to check consistency with the system boundaries, the data collection and their grouping in their corresponding category.[9, 15]

2.2.4.3 Conclusions, recommendations, and report

The final step of this phase is to draw conclusions form the results and recommend what is better to do with the focus of the study. To draw reliable conclusions, it is important to finish the previous phases because if not, the results might be inconclusive and the study itself would not have a valid meaning. Conclusions and recommendations must be drawn from the LCIA. The LCI does not provide the accuracy to obtain meaningful results.[9, 15]

2.3 Life Cycle Assessment Methodology Application

The methodology itself can be used for different kinds of industries. There have been studies involving food industry[16], construction industry[17], energy sector[13], manufacturing procedures, service industry, and education among many others. LCA has been diversified and adapted to different environments to look for the environmental impacts, measure them and assess them.

There has been little development in the area this research is focused. Certain studies have included a Benefit in the life cycle of a product. But these are related to cost benefits [17]. No other paper has shown exactly what is presented here, which is calculating the benefit of a product/service/process based on the needs of the customer. This looks to be promising in the way it is developed.

2.4 Summary

Current Life Cycle Assessment methodology consists of four phases: Goal and Scope, Inventory, Impact, and Improvement. If the first three phases are not done properly, then the last

phase would not be important because reliable results would not be obtained. The International Standards Organization created a series of standards in the 14000 series that deal specifically with the LCA methodology. This methodology is so powerful that it can be adapted to any kind of industry and still get the results of how product/service/procedures affect the environment and the human health. Very little research has been done in developing a Benefit Component for the LCA methodology. Development of benefits in terms of cost has been done for certain products. A benefit component based on what the customer needs and what an organization can provide has not been developed adequately.

3 BENEFIT ASSESSMENT METHODOLOGY

The Life Cycle Assessment (LCA) Benefit Assessment Methodology is based on the House of Quality tool of the Quality Function Deployment Methodology. This new assessment is similar to what is done in the house of quality. The main difference is the direction given at the end: the goal at the end is different.

3.1 Quality Function Deployment (QFD)

The Quality Function Deployment (QFD) is an overall concept that provides the necessary tools to translate the customer requirements into technical requirements in each stage of product development and production. Quality Function Deployment converts customer's needs into characteristics that can be measurable, determining quality levels for a product.[18] QFD is a way to capture, organize, and deploy the Voice of the Customer [19] — both the external and internal customers of the organization. QFD has often been associated with product development activities, manufacturing and developing a service. QFD is a method for developing products using design quality. To be effective, it must satisfy the consumers' needs. These needs or demands are translated into design targets and major quality assurance points. It is a way to ensure the design quality while the product is in the design stage.[20]

Yoji Akao developed Quality Function Deployment around 1966 in Japan. The first book in QFD was published in the Japanese language in 1978. It was later translated to English in 1994. The main objective of QFD is to take the wants and needs and translate them into technical characteristics to produce services and products that reach the customer satisfaction. By applying QFD to a design process, a person or company can have the benefits of [18, 21]:

- Increased customer satisfaction
- Reduced time to market
- Reduced costs for development and manufacturing
- Improved design reliability
- Information for competitive benchmarking
- Documentation of your product development process
- Clear direction for product improvement.

3.1.1 QFD Design Process Phases

QFD Design Process consists of four phases in which a product or service has to pass through to be developed correctly and efficiently. Figure 3.1 shows the QFD design process. The first phase is called product planning. It is the beginning of the House of Quality. In this phase, the entire customer's needs and demands are documented. It is very important to know that to be able to do the QFD of certain product or service is necessary to obtain the largest amount and most accurate data from the customer as possible. Not doing this would shift the focus of what the customer really wants.[18, 19, 22]

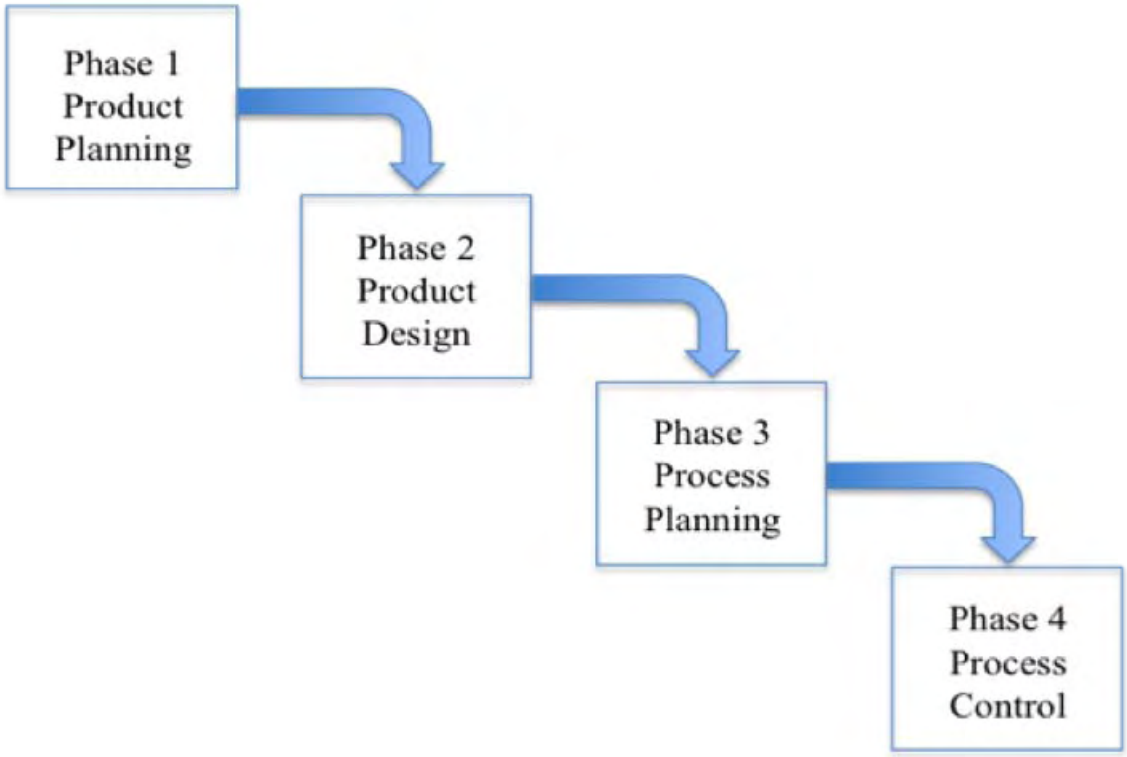

Figure 3.1 Phases of the QFD Design Process

The second phase of the QFD process is product design. The engineering department leads this phase. Product design requires a team of designers that use their creativity to produce innovative ideas. The concept of the product is created during this phase and the product's specifications are documented. The most important parts that meet the customer's need are then moved to the process planning phase.[18, 19]

The next phase in the QFD process is process planning. The manufacturing engineering department leads to this phase. During this phase, processes for manufacturing are flowcharted, process parameters are documented and target values are selected.[18, 19]

The last phase of the QFD process is the process control. The quality department and the manufacturing department are in charge of this phase. During this phase, important decisions are made about what processes are more risky and which controls should be enabled to prevent

failure. This phase consist of the creation of indicators to control the production process, the maintenance schedules, and training of the operators.[18, 19]

3.1.2 House of Quality Assembly

The first phase of the QFD process would be taken into consideration now. It is also known as the house of quality. It is a graphical tool used to define the relationship between what the customer wants or needs and what the company or person is capable to do. It uses a planning matrix to view how a company is going to meet those customer's needs. Now we will discuss the major components used in the house of quality.[19, 22]

- Customer Requirements

  The first major component in a QFD project is to determine the voice of the customer. During this process, the customers are identified and the market segments are selected. Information is gathered from the customers to know what are their demands and needs of a product or service. Using quality tools such as affinity diagrams or Tree Diagrams, the team organizes the data obtained from the customers.[19, 20]

- Customer Importance Ratings

  On a selected scale, customers then rate the importance of each requirement. This number will be used later in the relationship matrix.[23]

- Customer Rating of the Competition

  Knowing how customers rate a company's competition can give the company a competitive advantage. In this step, it is a good idea to ask customer show a product or service rates in relation to products or services of the competition. Other values that identify sales opportunities, goals for continuous improvement, customer complaints, etc., can be added in the rating.[18, 23]

- Technical Descriptors

  A technical descriptor is the voice of the engineer. Technical descriptors are attributes about the product or service that can be measured a company and could be benchmarked against the competition. Technical descriptors may exist in a organization used to determine product specification. However, new metrics can be created to ensure that the product is meeting customer needs.[19, 20]

- Relationship Matrix

  The relationship matrix determines the relationship between customer needs and a company's ability to meet those needs. This step answers how is the strength between the technical descriptors and the customer's needs. Relationships can be weak, moderate, or strong and carry a numeric value of 1, 3 or 9. [19, 20]

- Organizational Difficulty

  It could be possible that some attributes are in direct conflict. The design characteristics are rates in terms of organizational difficulty. Problems between technical descriptors may arise when the product is ready for manufacturing. Solving these problems before can prevent delays in the product.[18, 19]

- Technical Analysis of Competitor Products

  To better understand the competition, engineering conducts studies of the technical descriptors of the competition. This process involves reverse engineering of the competition's products to determine specific values for competitor technical descriptors.[18]

- Target Values for Technical Descriptors

  At this stage in the process, target values are determined for each technical

descriptor. Target values represent "how much" for each technical descriptors. This target vales can serve as a base line to compare against.[18]

- Correlation Matrix

  This step in the matrix is where the term House of Quality comes from because it makes the matrix look like a house with a roof. The correlation matrix is the least used room in the House of Quality; however, this step is a big help to the design engineers in the next phase of a QFD project. Technical descriptors are examined to see how each of them impacts each other. This should be documented to identified strong negative relationships between technical descriptors and work to eliminate physical problems.[18]

- Absolute Importance

  The absolute importance for each technical descriptor is calculated in this step. This numerical calculation is the product of the cell value and the customer importance rating. Numbers are then added up in their respective columns to determine the importance for each technical descriptor. Now, you could know which technical aspects of the product matters the most to the customer.[18]

These are the typical components of a House of Quality. Combining these components, the following figure can be obtained [24]:

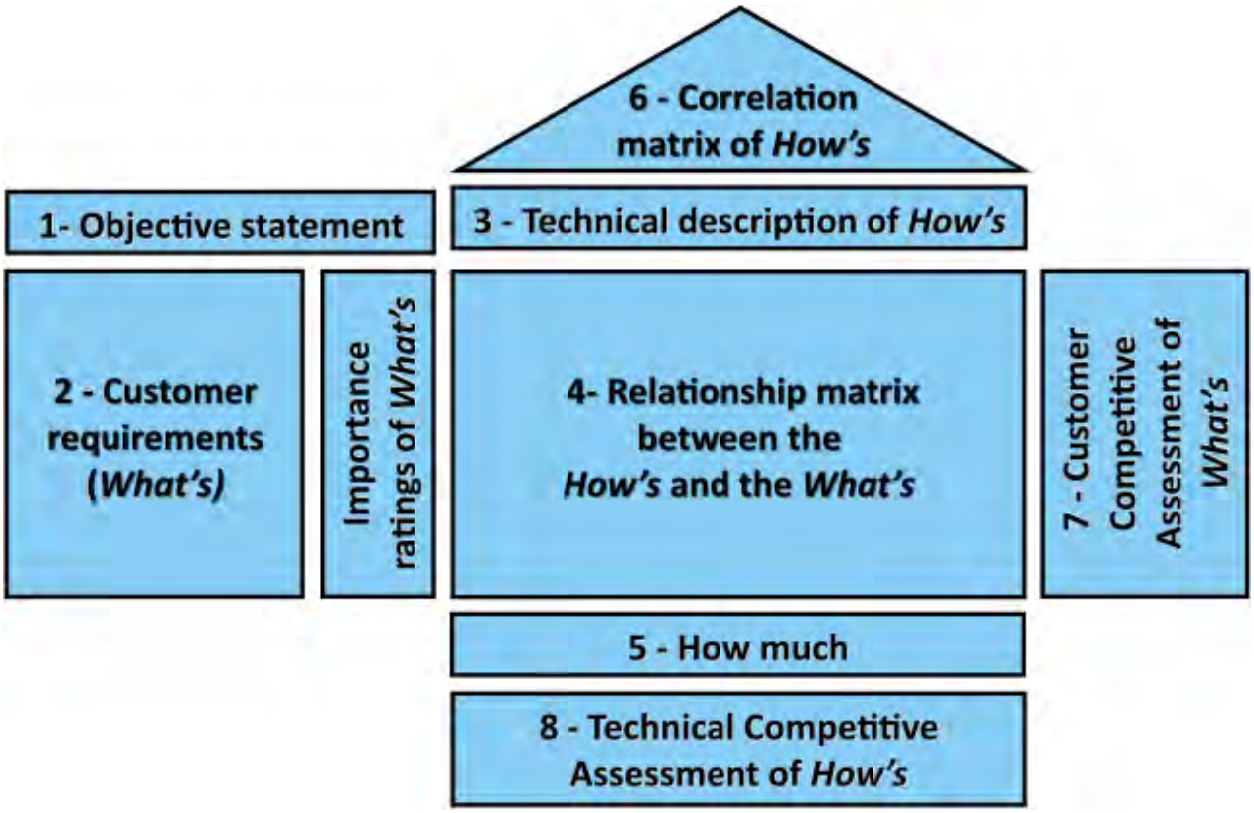

Figure 3.2 Typical schematic of House of Quality

As the design process continues, the step of the HOQ for each process is repeated but in a simplified way, until all the phases are completed. In phase 2, the voice of the engineer is translated into the voice of design specification. In phase 3, the design specification is translated into the voice of manufacturing planning. Finally, in phase 4, the manufacturing planning is translated into the voice of production planning. It is important to know that each phase will be done apart but having all the people of the project involved in.[18, 23]

3.2 Developing a Benefit Assessment Methodology using Quality Function Deployment

For now, the QFD and what can be done with it has been explained. The proposed LCA Benefit Assessment Methodology uses QFD as part of the analysis, and in addition the overall benefits are combined in a single benefit index. This new Benefit Assessment methodology can

be applied to a product or service, in order to assess the benefit of having or producing certain product or certain service. The development of this methodology is presented next step-by-step, along with an explanation of what it produces at the end.

The first step of the methodology is *Product/Service Selection Step*. In this step, the object of the investigation is selected. The product or service must be described thoroughly. This is an important step because it may reveal important information that may not seem obvious to the user and that might be useful at some time during the methodology process.

After describing the product or service to be evaluated, the next step in the methodology is *Customer Identification and Needs Step*. Here, the customer is identified along with the customers' needs with respect to the product or service. This is one important step, since the whole methodology is based on what a customer expects from the product or service. In this step the voice of the customer, who the customers are, and what are their needs will be determined. Information is gathered through various quality tools such as affinity diagrams or tree diagrams.

An affinity diagram is a tool that collects a large quantity of qualitative data and organizes the data into various groups. Language data can be ideas, opinions, and issues, among others, that a person can creatively think of. This organization is based on the relationship that might exist between each group. This tool induces creative thinking rather than the traditional one. This is important because no idea would be lost when grouping them. The figure below shows an schematic of how an affinity diagram looks at then end.[19, 23]

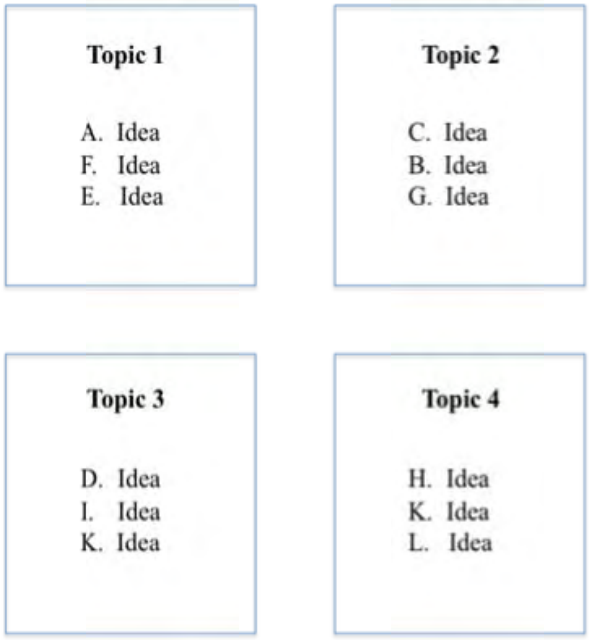

Figure 3.3 Affinity Diagram

Another quality tool that can be used in this step is the tree diagram. This is a tool that provides a full view of the tasks needed to achieve the main goal. A service can imply a variety of processes in order to provide it. In the case of evaluating a service, the tree diagram can portray what would be the different processes required to completely meet the customer needs and focus on what is more important to the customer. There are several ways to view this tool. The figure below shows a possible representation of a tree diagram.[19, 23]

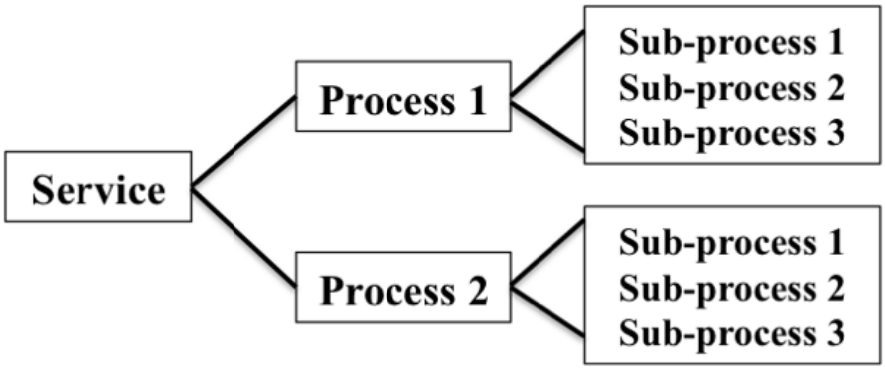

Figure 3.4 Tree Diagram

Vital information obtained using these tools is categorized and arranged in table form. The next step will use this data to obtain certain values needed for the methodology. Since we are talking about needs, the table should resemble the figure below.

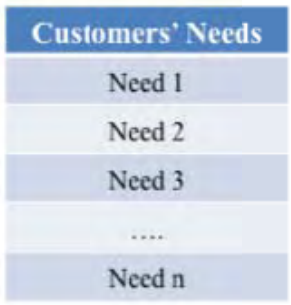

Figure 3.5 Data selected from the customer

The next step in the methodology is the calculation of the *Customer Importance Rating*. In this step, the customer rates, from a list of needs, the importance of each need in comparison with other needs. This would create a matrix that would calculate this number. To create this matrix, each need will be compared to other needs in the following form:

Table 3.1 Digital Logic Matrix

	Need 1	Need 2	. . .	Need n
Need 1				
Need 2				
…				
Need n				

To fill this table, values of 1, 0.5, and 0 will be used.

- 1 - Need is more important than the one being compared to
- 0.5 - Need has same importance as the one being compared to
- 0 - Need is less important than the one being compared to

For example, consider the case that Need 1 is more important than Need 2. Then, a value of 1 inserted in the corresponding cell in the matrix (intersection of the row of Need 1 with the

column of Need 2). After the entire matrix is filled, then two other columns will be added to the right of the last column. The first column being added represents the sum of all the values to the right. All values will be added for each need. Then, the sum of all values will be calculated and later, a corresponding percent for each Need will be obtained. This percent will indicate which need is more important than others. Using this type of method will truly show the voice of the customer as an important component when designing a product or service.

The next step in the methodology is the *Listing of Performance Measurements*. A performance measurement is a technical measurement used to evaluate the performance of a service or a product. For each customer's need, at least one performance measurement must be established. This is very important to be able to evaluate different designs while at the same time having in mind the customer's desires. This is one of the most challenging parts of this methodology. It is not easy since one has to translate what the customer wants into engineering terms.[19] For example, a designer wants to design a new chair. A customer may say that he or she wants it to be comfortable. Since the designer is a customer, he or she should understand what does the customers means by saying comfortable. The designer may ask himself or herself how do I translate comfortable into an engineering term. It is very difficult to do so, especially when the customer has one definition of comfortable and the designer has another. In our case, a designer must then choose performance measurements that the company, program, or institution can provide, having in mind what were the customers' needs. As for the customer's requirement, the data should be organized in table form as seen below:

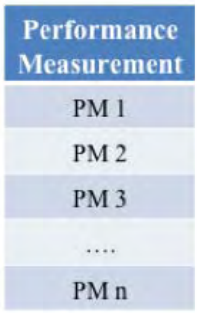

Figure 3.6 Performance Measurements

The following step in the methodology is *Selecting Target Values*. Target values are optimal values selected for each performance measurement. Without a proper selection of these values, there would not be any importance doing this methodology. These values would represent the metric needed to fulfill each performance measurement.

After finishing the performance measurement, the next step in the methodology is to fill in the *Relationship Matrix*. The relationship matrix defines the relationship between a customer's need with a performance measurement; and in the case there is a relationship, it ranks the relationship as strong, medium, or weak. The strength of the relationship is rated according to the following scale [20]

- 9 - strong relationship
- 3 - medium relationship
- 1 - weak relationship
- 0 - no relationship

There are different ways to assign the value of the corresponding relationship. Some rely on personal judgment for selecting the value that best describes the relationship. Another way to assign the values is to use a focal group of customers, and have them assign values and justify their decisions. Another way to assign the values is to use a panel composed of different subject matter experts to evaluate the relationships.

After the relationship matrix is completed, a *Correlation Matrix* can be done for the purpose of viewing if any problem could arise between each performance measurement. The designer uses the Correlation Matrix to determine if there is a problem between each performance measurement when trying to fulfill the customer's needs. Although this part doesn't influence the final value of the benefit, it is a way to improve on what they have to offer.

The final step of this methodology is the *Benefit Index Calculation.* To determine this index, several calculations must be completed. These include an absolute importance value and a relative importance value. The figure below describes the filling of the values in the House of Quality.

Table 3.2 Benefit Index calculation table

	Performance Measurement 1	**Performance Measurement 2**	**Performance Measurement 3**	**Performance Measurement 4**	**Performance Measurement 5**	**Customer importance**
Need 1	a_1	a_2	a_3	a_4	a_5	Z_1
Need 2	b_1	b_2	b_3	b_4	b_5	Z_2
Need 3	c_1	c_2	c_3	c_4	c_5	Z_3
Need 4	d_1	d_2	d_3	d_4	d_5	Z_4
Need 5	f_1	f_2	f_3	f_4	f_5	Z_5
Absolute Importance	g_1	g_2	g_3	g_4	g_5	$\sum G$
Relative Importance	h_1	h_2	h_3	h_4	h_5	

What it must kept in mind when filling this matrix is that values for a_n, b_n, c_n, d_n, and f_n are numbers that can be 0, 1, 3, and 9. Values for Z_n are calculated using the Digital Logic Matrix. To calculate the absolute importance, we will use the following equation,

$$Absolute\ \_ impor\ \tan ce = g_j = \sum_i a_j Z_i \quad \textbf{(3.1)}$$

For each value of g, the absolute importance, a value will be calculated. Values of Z will be the same for each value of g. After calculating the absolute importance values, the next step will be to sum all the values of g as follows,

$$G = \sum g_n \quad \textbf{(3.2)}$$

Then, the relative importance will be calculated using the values obtained of the absolute importance. To calculate the relative importance (h_n), the following equation is used,

$$h_j = \frac{g_j}{\sum_i g_i} * 100 \quad \textbf{(3.3)}$$

All the values of the relative importance (h) would have to sum up to 100 at the end of the normalization process. This relative importance is our importance factor. This number would tell us what performance measurement is more important to work in to get maximum customer satisfaction. In another way, it tells us which performance measurement is more important to the customer and which should one emphasize in.

The final procedure in the Benefit Index Calculation step is to calculate the index itself. To do this, the following equation will be used:

Benefit Index = ΣTarget Value*Relative Importance Value **(3.4)**

This score describes the overall benefit a customer would obtain from a given product or service. On this scale, a value of 100 represents the ideal product that completely satisfies the needs of the customer; a value of 0 describes a product or service that does not meet any of the needs of the customer.

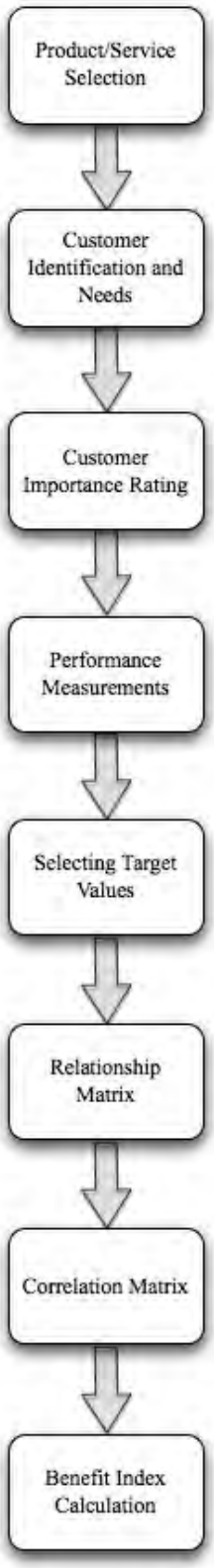

Figure 3.7 Flowchart of the steps in the Benefit Assessment Methodology

The Benefit Index allows developers of products and services to understand how well the their product or service addresses the overall combined needs of the customer. The use of the Benefit Index, along with the assessment of the environmental impacts, will provide developers with a tool to understand how design changes can affect the environmental impact of a product or service while at the same time understand how these same changes can affect how the needs of the customer are met. It could be possible that the customer's needs could create a conflict with the environmental impacts of a product. Since this Benefit Index would be part of a cycle in the LCA, the overall assessment of benefits and impacts are done continuously to find the best combination between what the benefits of the product or service and the impacts they create when they are produced. This is a tool for developing environmentally friendly products that can successfully compete in the marketplace.

3.3 Summary

In this chapter, background information about Quality Function Deployment was given. Also, a typical guide of the necessary steps of the House of Quality was presented. The Benefit Assessment Methodology was based on the House of Quality tool. Each step developed in the methodology was explained in detail to provide a better understanding of how is the methodology structured.

4 BENEFIT ASSESSMENT METHODOLOGY APPLICATION

In the previous chapter, the benefit assessment methodology was discussed. In order to validate it and demonstrate its use it will be applied to a product or service to see the results. In this chapter the methodology will be applied to an air conditioner (product) and to a chemistry laboratory (service). In this way, information will be collected from customers to be used in the methodology to determine the benefit that can be obtained from a product and the benefit that can be obtained from a service. The main goal of this research is to develop this methodology. These two examples are done only to see how the methodology behaves when applied to a product or a service. It is important to keep in mind that the product and service selected serve only as a way to see if the methodology developed serve its purpose; it is not a step-by-step guide of how to use the methodology in the product or the service selected.

4.1 Product: Air Conditioner

A room air conditioner is a common product that any person can purchase to cool and dehumidify indoor air for thermal comfort. In the past, the acquisition of a room air conditioner was considered a luxury, but, nowadays, in some places it is considered an essential product for the comfort of any person. This change of point of view of the consumer may be the result of the improvements that AC designers and manufacturers have developed to increase the energy efficiency and to lower the product's cost.

Since the industrial revolution, the world climate has changed. The burning of fossil fuels and the pollution of industries has added to the creation of greenhouse gasses. The greenhouse gasses prevent that some solar irradiation (sunlight) escape from the Earth's atmosphere to the space. To avoid the hot temperatures, the marketplace demand of an air conditioner has grown up rapidly.

To be able to deliver an excellent product that can satisfy the needs of the consumer, the manufacturer has to develop a good design method. Using the benefit assessment methodology, the real needs of a customer when he/she thinks of an air conditioner can be taken into account. With these needs and what a company can provide when making an air conditioner, the benefit assessment can be calculated completely. Then, with the benefit index, a company can make a better design by satisfying the customer's needs and by providing a great variety of benefits.

4.1.1 Product Overview

A room air conditioner is defined as a device installed through a wall, a window, or as a console. The room air conditioner is defined in the United States as a single-piece unit that can perform other functions such as ventilation and heating [25]. The assembly of a room air conditioner consists mainly of a chassis, upon which an enclosure is mounted. The main parts of the room air conditioner are condenser, evaporator coil, tubes, circuits, filter, control panel, compressor and fans [26]. The common materials used in the manufacture process are aluminum, copper, steel, and plastic [26]. In the figure below, a photo of an air conditioner is provided with all its parts labeled.

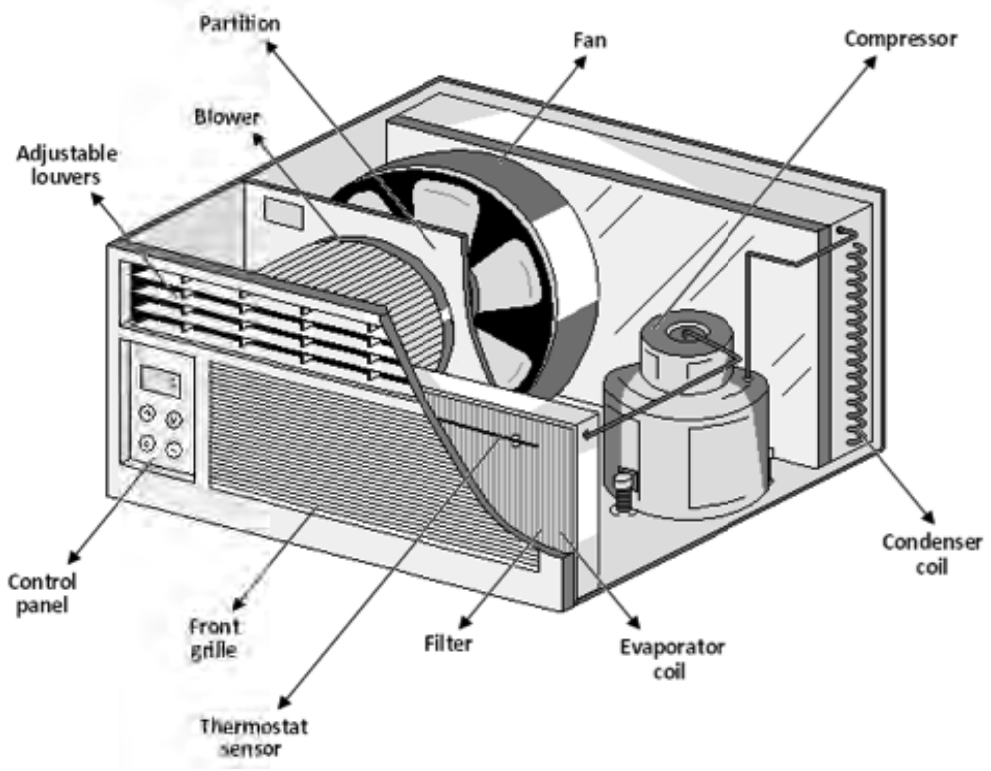

Figure 4.1 Air conditioner schematic

4.1.2 Methodology Application

The first step in the Benefit Assessment Methodology is the selection of the product for which the benefits will be evaluated, which in this case the product selected was the room air conditioner. Once the product was selected, the evaluation of the customer needs was initiated. As explain before, this is not a guide to follow of a benefit assessment of an air conditioner. Only certain aspects were used to see how the methodology behaves when applied to this product. A more profound assessment is needed to create a more valid benefit index. A sample group of 25 persons, males and females in a range of age between 18 and 25 were asked about what were their desires and needs when considering an air conditioner. This was done to gather information on the requirements people would want or like for an air conditioner. After gathering the information, data was tabulated. In the table below we can see a total of 18 needs or desires that most customers would want.

Table 4.1 Consumers' needs

Costumers' needs	
Low Cost (price)	Easy to install
Air quality (fresh Air system)	Product life, durability and confidence
Size	Features
Easy to use	Warranty
Energy consumption (kW*hr)	The size of the room that can be air conditioned by the system
Esthetics, style, appearance	Digital system
Work properly	Maintain a regulated temperature
Work silently	Remote control feature
Maintains humidity	Directional control of the air flow

From the list above, as a way to demonstrate this methodology, the most repeated needs were the ones that were selected for this application. The table below shows the customers' needs selected.

Table 4.2 Customers' needs selected

Customers' Needs
Work silently
Air quality (fresh air system)
Maintains humidity
Maintain a regulated temperature
Directional control of the air flow
Low cost (price)
Energy consumption (kW*hr)
Warranty
Size
Easy to use
Esthetics, style, appearance
Digital system

After selecting the most important needs that customers' would like, they rated which were more important than others. Each need was compared to other needs to rate their importance using the Digital Logic Method. The customer importance rating for each need is listed in Table 4.4. Values of percent are the values of importance for each need.

After calculating the Customer Importance Rating, research about the air conditioner was done. This is necessary for the analysis process. Information such as technical specifications, material properties, standards, and indicators, among many others were gathered together to get a better understanding of the product. These technical specs represent the Performance Measurements. These metrics are what a company can provide to produce the air conditioner. Table 4.3 shows the Performance Measurements for the air conditioner.

Table 4.3 Performance Measurement

Performance Measurement
EER
Power Consumption
Weight
Control System
Retail Cost
Noise Testing
Dimensions
AC Standards
COP
Service Contract
Humidity
Air Quality

Table 4.4 Digital logic matrix for the air conditioner

	Work silently	Air quality	Maintains humidity	Maintain a regulated temperature	Directiional control of the air flow	Low cost	Energy consumption	Warranty	Size	Easy to use	Esthetics, style, appearance	Digital system	Summatory	Percentage
Work silently	----	0.5	1	0.5	1	0	0	1	0.5	1	1	1	7.5	11.36
Air quality (fresh Air system)	0.5	----	0.5	0.5	1	0	0	1	0.0	0.5	0.5	1	5.5	8.33
Maintains humidity	0	0.5	----	0.5	0.5	0	0	1	1.0	1	1	1	6.5	9.85
Maintain a regulated temperature	0.5	0.5	0.5	----	0.5	0	0	1	1.0	1	1	0	6	9.09
Directional control of the air flow	0	0	0.5	0.5	----	0	0	0.5	0.5	0.5	0.5	0.5	3.5	5.30
Low Cost (price)	1	1	1	1	1	----	0.5	1	1.0	1	1	1	10.5	15.91
Energy consumption (kW*hr)	1	1	1	1	1	0.5	----	1	1.0	1	1	1	10.5	15.91
Warranty	0	0	0	0	0.5	0	0	----	1.0	1	1	1	4.5	6.82
Size	0.5	1	0	0	1	0	0	0	----	0.5	0.5	1	4	6.06
Easy to use	0	0.5	0	0	0.5	0	0	0	0.5	----	1	1	3.5	5.30
Esthetics, style, appearance	0	0.5	0	0	0.5	0	0	0	0.5	0	----	0.5	2	3.03
Digital system	0	0	0	1	0.5	0	0	0	0	0	0.5	----	2	3.03
												Total	**66**	**100**

Next step in the methodology is the Relationship Matrix. This matrix represents how a customer's need relates to a Performance Measurement. Values of 0, 1, 3, and 9 represent how is the relationship. A value of 0 shows that there is no relationship. A value of 1 shows a weak relationship. A value of 3 shows a medium relationship. A value of 9 shows a strong relationship. To fill this matrix, people with the knowledge in the subject, mainly designers, should do this exercise. To create the relationship matrix, the person asks himself/herself how is the relationship between one need and a performance metric. Form the values before, 4 possible answers can describe the relationship. Is the relationship strong? Is it medium? Is it weak? Is there any relationship between the need and the performance metric? Each need will be compared to every performance metric. Values will be assigned to each cell. As a matter of example, the relationship matrix for the air conditioner example is shown below.

Table 4.5 Relationship matrix

	Performance Measurements / **Customers' Needs**	EER	Power Consumption	Weight	Control System	Retail Cost	Noise testing	Dimension	AC Standards	COP	Service Contract	Humidity	Air Quality
Comfort	Work silently	0	0	1	0	3	9	1	0	1	0	0	0
	Air quality (fresh Air system)	0	3	0	0	3	0	0	3	0	0	3	9
	Maintains humidity	1	1	0	9	1	0	0	9	1	0	9	9
	Maintain a regulated temperature	9	3	0	9	1	0	0	9	1	0	9	0
	Directional control of the air flow	0	1	0	1	3	3	0	0	1	0	0	0
Economy	Low Cost (price)	9	9	1	1	9	3	9	0	3	9	1	9
	Energy consumption (kW*hr)	9	9	0	1	9	0	9	9	9	0	0	0
	Warranty	0	0	0	0	9	0	0	0	0	9	0	0
Features	Size	0	3	9	0	1	9	9	0	0	0	0	0
	Easy to use	0	0	0	1	1	0	0	0	0	0	0	0
	Esthetics, style, appearance	0	0	9	0	1	0	9	0	0	0	0	0
	Digital system	0	0	0	1	1	0	0	0	0	0	0	0

After completing the relationship matrix, the final step is the Benefit Index Calculation. In this step, all the equations presented in Chapter 3 will be used to calculate the desired index.

First, equation 3.1 was used to calculate the absolute importance of each performance measurement. Later, using equation 3.2, the sum of all values of the absolute importance was calculated. After obtaining that value, and using equation 3.3, the relative importance for each performance measurement was calculated. Using this percentage, it is multiply with the target values selected to obtain the benefit in each performance measurement. Later, using equation 3.4, the benefit index was calculated. In table 4.8, the final matrix is presented with all the values of the Benefit Index for each Performance Measurement.

Table 4.6 presents each Performance Measurement with its corresponding percent of the entire benefit system. For instance, the whole air conditioner system represents the 100%. Retail Cost represents 13.4 % of the entire air conditioner. According to the customers, retail cost is more important than other performance measurements when they are going to buy an air conditioner. If manufacturers lower the cost of the air conditioner, they could satisfy better the customer by providing lower retail prices. Customer will go and buy air conditioners that satisfy their needs, having a more beneficiary product.

Table 4.6 Benefit percent for each Performance Measurement

Performance Measurements	% Importance
EER	11
Power Consumption	10.9
Weight	3.2
Control System	6.3
Retail Cost	13.4
Noise Testing	6.4
Dimensions	11.1
AC Standards	9.9
COP	6.6
Service Contract	6
Humidity	6.2
Air Quality	9

This percentage could be used to calculate the Benefit Index for a given air conditioner unit. For instance, for each performance measurement there is a performance score between 0 and 100 that reflects what is the performance right now or the capacity of a company to achieve that performance measurement. If we multiply the percentage of importance by its corresponding score and add this up, we can obtain what is the benefit index for the entire air conditioner using equation 3.4. Table 4.7 shows this example.

Table 4.7 Example of Benefit Index

Performance Measurements	% Importance	Score (1-100)	Benefit
EER	11	20	2.2
Power Consumption	10.9	45	4.9
Weight	3.2	67	2.1
Control System	6.3	35	2.2
Retail Cost	13.4	76	10.2
Noise Testing	6.4	22	1.4
Dimensions	11.1	90	10.0
AC Standards	9.9	54	5.3
COP	6.6	83	5.5
Service Contract	6	56	3.4
Humidity	6.2	70	4.3
Air Quality	9	65	5.9
		Benefit Index	**57**

As it can be seen above, if the score of EER is improved, the benefit for that performance measurement will increase and the overall benefit index for the air conditioner will also increase.

Table 4.8 Benefit Assessment matrix

	Performance Measurements / Customers' Needs	EER	Power Consumption	Weight	Control System	Retail Cost	Noise testing	Dimension	AC Standards	COP	Service Contract	Humidity	Air Quality	**Importance**
Comfort	Work silently	0	0	1	0	3	9	1	0	1	0	0	0	11.4
	Air quality (fresh Air system)	0	3	0	0	3	0	0	3	0	0	3	9	8.3
	Maintains humidity	1	1	0	9	1	0	0	9	1	0	9	9	9.8
	Maintain a regulated temperature	9	3	0	9	1	0	0	9	1	0	9	0	9.1
	Directional control of the air flow	0	1	0	1	3	3	0	0	1	0	0	0	5.3
Economy	Low Cost (price)	9	9	1	1	9	3	9	0	3	9	1	9	15.9
	Energy consumption (kW*hr)	9	9	0	1	9	0	9	9	9	0	0	0	15.9
	Warranty	0	0	0	0	9	0	0	0	0	9	0	0	6.8
Features	Size	0	3	9	0	1	9	9	0	0	0	0	0	6.1
	Easy to use	0	0	0	1	1	0	0	0	0	0	0	0	5.3
	Esthetics, style, appearance	0	0	9	0	1	0	9	0	0	0	0	0	3.0
	Digital system	0	0	0	1	1	0	0	0	0	0	0	0	3.0
Weighted Importance		378.0	372.0	109.1	215.9	459.1	220.5	379.5	338.6	226.5	204.5	211.4	306.8	**3422**
% Importance		11.0	10.9	3.2	6.3	13.4	6.4	11.1	9.9	6.6	6.0	6.2	9.0	**100**

4.2 Service: Chemistry Laboratory

The service industry is very important to the economy. Many organizations provide their services to people to satisfy a need or a group of needs. This need might be one in a lifetime or it might be recurrent. For example, a taxi service is a need for people in New York City. Many people living there don't buy or don't have cars. They rely on the service of using a taxi to move form place to place. Organizations try to improve their services to ultimately have a loyal customer that could always come to them to satisfy their needs. In this part, the use of the Benefit Assessment methodology will be applied to a service to see how it can be implemented to this type of commerce.

4.2.1 Service Overview

The service evaluated for this part will be a chemistry laboratory. Although it is not commercial service, it is service provided by the University to first-year undergraduate students. Providing this service requires the use of raw materials, energy, personnel, equipment and space. This kind of laboratory is unique. It is the first laboratory experience a student takes when starting a degree in science, engineering, or business. For some universities, it is a requirement for all undergraduate students. Focusing on a chemistry student, this laboratory will be a rewarding experience since it will show the student the first steps into the chemistry world. The student will learn the basic tools that will later be applied to other courses in a chemistry degree.

4.2.2 Methodology Application

A chemistry course teaches the student the theory needed to understand what chemistry is. The experiences of the chemistry laboratory will complement the theory presented in the classroom. This provides practical knowledge that cannot be learned in a normal chemistry class. Hands-on experience will prepare the student better with a set of skills that will help them

in a near future. This chemistry laboratory is located in the University of Puerto Rico – Mayagüez Campus (UPRM), in the Department of Chemistry. This laboratory is part of a theoretical course that offers the students basic principles of chemistry and how to use them. It is important to mention that, as in the product implementation of the methodology, this service selected serves as a demonstration of how the methodology behaves when applied to a service. It is not a step-by step procedure of what to do or include when dealing with this type of service. For a specific detail of the benefit of having a chemistry laboratory, a mire profound study should be made to include other parameters that affect the overall benefit.

The first step of the Benefit Assessment Methodology is selecting the service. In this case, the service is already selected: chemistry laboratory. After selecting the service, research of what is the service, what it does, what is its purpose, and what it comprises must be done.

Next in the methodology is determining the customer's needs. In this case, the customer is a undergraduate student that has taken previously the laboratory. First-year student don't know exactly what is the laboratory. The use of the experience of students that have taken the laboratory should be helpful for those students that are going to take it. Since this laboratory experience will not be new to him/her, the student can provide great feedback of what he/she would want from the laboratory. A sample size of 10 students was used in this example. Participants included both males and females, selected randomly, from second to fifth year in the university.. For a more profound study, a bigger sample size should be determined. This is for demonstration only. Table 4.9 shows needs of the students toward a chemistry laboratory.

Table 4.9 Students' needs selected

Students' Needs
Learn how to use the laboratory equipment
Learn the basic rules of laboratory safety
Be able to work as a group
Learn to make lab reports
Learn how to make the appropriate measures
Learn more about the Chemistry course through the lab
Good equipment for the laboratory
Discuss class material before the laboratory
Relate the laboratory with the industry.
The instructor should be able to manage the time of the laboratory course
Receive feedback from the instructor
Good communication between the instructor and the student
Good labeling of the area
Safety equipment
Equipment clean and ready for use

After selecting the students' needs, the students would have to rate the importance for each need using the digital logic matrix. This will be done as in the previous example. A value of 1, 0.5, and 0 will be used to rate the needs. At the end, a weighting factor will be obtained, characterizing the needs. Table 4.10 shows the calculated importance rating for each need of the students.

After obtaining the importance rating for each need, the next step in the process is listing the Performance Measurements. With this, it can be documented what the chemistry laboratory can offer the students. Table 4.11 shows the performance measurements for a chemistry laboratory at UPRM.

Table 4.10 Importance rating for each need

Students' Needs	Importance Rating
Learn how to use the laboratory equipment	**5.26**
Learn the basic rules of laboratory safety	**3.35**
Be able to work as a group	**3.35**
Learn to make lab reports	**6.70**
Learn how to make the appropriate measures	**6.70**
Learn more about the Chemistry course through the lab	**5.74**
Good equipment for the laboratory	**7.66**
Discuss class material before the laboratory	**6.22**
Relate the laboratory with the industry.	**5.74**
The instructor should be able to manage the time of the laboratory course	**6.70**
Receive feedback from the instructor	**5.74**
Good communication between the instructor and the student	**5.26**
Good labeling of the area	**11.96**
Safety equipment	**12.44**
Equipment clean and ready for use	**7.18**

Table 4.11 Performance measurements for the chemistry laboratory at UPRM

Performance Measurements
Section size
Instructor experience in the course
Number of students that pass the lab course
Equipment available
Office hours
How prepared is the laboratory for its use
Lab capability to attend students with special needs
Evaluations - Quizzes
Evaluations - Midterms
The security equipment is the necessary and updated
Enough material for all students
Visual aids in the laboratory
Clean laboratory
Waste management
Environmental controls

After selecting the performance measurements, the next step in the methodology is completing the relationship matrix. As for the previous example, it will be filled with values of 0, 1, 3, and 9. Each need will be compared to every performance measurement to establish the relationship between them. A value of 9 represents a strong relationship between a need of the student and a performance measurement of the service. A value of 3 represents a medium relationship between a need and a performance measurement. A value of 1 represents a weak relationship between a need and a performance measurement. Table 4.12 shows the relationship matrix once it has been completed.

After obtaining the relationship matrix, the next step will be the Benefit Index Calculation. Equations from chapter 3 will be used to obtain the desired values. First, equation 3.1 was used to calculate the absolute importance of each performance measurement. Later, using equation 3.2, the sum of all values of the absolute importance was calculated. After obtaining that value, and using equation 3.3, the relative importance for each performance measurement was calculated. Using this percentage, it is multiply with the target values selected to obtain the benefit in each performance measurement. Later, using equation 3.4, the benefit index was calculated. Table 4.13 presents the house of quality and the final values obtained form the calculations of the benefit. Table 4.14 shows the values for each Performance Measurement. Each value presents the importance of each performance measurement according to the needs of the students.

Table 4.12 Relationship matrix for the chemistry laboratory at UPRM

	Section size	Instructor experience in the course	Number of students that pass the lab course	Equipment available	Office hours	How prepared is the laboratory for its use	Lab capability to attend students with special needs	Evaluations - Quizzes	Evaluations - Midterms	The security equipment is the necessary and updated	Enough material for all students	Visual aids in the laboratory	Clean laboratory	Waste management	Environmental controls
Learn how to use the laboratory equipment	9	9	1	3	1	1	0	3	3	9	9	1	0	3	0
Learn the basic rules of laboratory safety	0	3	0	0	1	3	0	1	1	9	3	3	0	9	0
Be able to work as a group	9	0	9	1	0	1	3	0	0	0	1	3	0	0	0
Learn to make lab reports	0	9	1	0	3	0	0	0	0	0	0	3	0	0	0
Learn how to make the appropriate measures	0	9	3	1	1	0	3	3	3	3	9	3	0	0	0
Learn more about the Chemistry course through the lab	1	9	3	3	3	1	1	9	9	0	1	9	0	0	0
Good equipment for the laboratory	0	0	3	9	0	9	1	0	0	9	3	1	9	3	3
Discuss class material before the laboratory	0	9	9	0	1	0	3	9	9	1	0	9	0	0	0
Relate the laboratory with the industry.	0	3	1	1	0	1	1	1	1	1	0	1	0	0	0
The instructor should be able to manage the time of the laboratory course	3	9	3	0	0	0	9	0	0	0	0	0	0	0	0
Receive feedback from the instructor	1	1	9	0	9	0	9	3	3	1	0	0	0	0	0
Good communication between the instructor and the student	9	1	3	0	9	0	9	1	1	1	0	0	0	0	3
Good labeling of the area	0	0	0	3	0	9	0	0	0	9	1	1	1	9	0
Safety equipment	0	0	0	9	0	9	0	0	0	9	9	0	3	9	0
Equipment clean and ready for use	0	0	0	9	0	9	0	0	0	3	9	0	9	9	0

Table 4.13 Benefit Assessment final values

	Section size	Instructor experience in the course	Number of students that pass the lab course	Equipment available	Office hours	How prepared is the laboratory for its use	Lab capability to attend students with special needs	Evaluations - Quizzes	Evaluations - Midterms	The security equipment is the necessary and updated	Enough material for all students	Visual aids in the laboratory	Clean laboratory	Waste management	Environmental controls	% Importance
Learn how to use the laboratory equipment	47.8	47.8	5.3	15.9	5.3	5.3	0.0	47.8	47.8	5.3	15.9	5.3	5.3	0.0	47.8	47.8
Learn the basic rules of laboratory safety	0.0	5.8	0.0	0.0	1.9	5.8	0.0	0.0	5.8	0.0	0.0	1.9	5.8	0.0	0.0	5.8
Be able to work as a group	8.7	0.0	8.7	1.0	0.0	1.0	2.9	8.7	0.0	8.7	1.0	0.0	1.0	2.9	8.7	0.0
Learn to make lab reports	0.0	34.7	3.9	0.0	11.6	0.0	0.0	0.0	34.7	3.9	0.0	11.6	0.0	0.0	0.0	34.7
Learn how to make the appropriate measures	0.0	34.7	11.6	3.9	3.9	0.0	11.6	0.0	34.7	11.6	3.9	3.9	0.0	11.6	0.0	34.7
Learn more about the Chemistry course through the lab	2.4	21.8	7.3	7.3	7.3	2.4	2.4	2.4	21.8	7.3	7.3	7.3	2.4	2.4	2.4	21.8
Good equipment for the laboratory	0.0	0.0	8.7	26.1	0.0	26.1	2.9	0.0	0.0	8.7	26.1	0.0	26.1	2.9	0.0	0.0
Discuss class material before the laboratory	0.0	60.8	60.8	0.0	6.8	0.0	20.3	0.0	60.8	60.8	0.0	6.8	0.0	20.3	0.0	60.8
Relate the laboratory with the industry.	0.0	21.8	7.3	7.3	0.0	7.3	7.3	0.0	21.8	7.3	7.3	0.0	7.3	7.3	0.0	21.8
The instructor should be able to manage the time of the laboratory course	26.1	78.3	26.1	0.0	0.0	0.0	78.3	26.1	78.3	26.1	0.0	0.0	0.0	78.3	26.1	78.3
Receive feedback from the instructor	9.7	9.7	86.9	0.0	86.9	0.0	86.9	9.7	9.7	86.9	0.0	86.9	0.0	86.9	9.7	9.7
Good communication between the instructor and the student	86.9	9.7	29.0	0.0	86.9	0.0	86.9	86.9	9.7	29.0	0.0	86.9	0.0	86.9	86.9	9.7
Good labeling of the area	0.0	0.0	0.0	34.8	0.0	104.3	0.0	0.0	0.0	0.0	34.8	0.0	104.3	0.0	0.0	0.0
Safety equipment	0.0	0.0	0.0	113.0	0.0	113.0	0.0	0.0	0.0	0.0	113.0	0.0	113.0	0.0	0.0	0.0
Equipment clean and ready for use	0.0	0.0	0.0	113.0	0.0	144.0	0.0	0.0	0.0	0.0	113.0	0.0	144.0	0.0	0.0	0.0
Σ	181.6	325.1	255.6	322.2	210.6	409.2	299.5	181.6	325.1	255.6	322.2	210.6	409.2	299.5	181.6	325.1
Percentage %	**4.8**	**8.6**	**6.7**	**8.5**	**5.6**	**10.8**	**7.9**	**4.8**	**8.6**	**6.7**	**8.5**	**5.6**	**10.8**	**7.9**	**4.8**	

Table 4.14 Benefit percentage for each performance measurement

Performance Measurements	% Importance
Section size	4.8
Instructor experience in the course	8.6
Number of students that pass the lab course	6.7
Equipment available	8.5
Office hours	5.6
How prepared is the laboratory for its use	10.8
Lab capability to attend students with special needs	7.9
Evaluations - Quizzes	4.2
Evaluations - Midterms	4.2
The security equipment is the necessary and updated	10.3
Enough material for all students	8.9
Visual aids in the laboratory	3.7
Clean laboratory	5
Waste management	9.8
Environmental controls	1

This percentage could be used to calculate the Benefit Index for a Chemistry laboratory. For instance, for each performance measurement there exists a score for between 0 and 100 that reflects what is the performance right now. If we multiply the percentage of importance by its corresponding score and add this up, we can obtain what is the benefit index for the entire chemistry laboratory. Table 4.15 shows the results for this example.

Table 4.15 Benefit Index example

Performance Measurements	% Importance	Score (1-100)	Benefit
Section size	4.8	20	0.96
Instructor experience in the course	8.6	45	3.87
Number of students that pass the lab course	6.7	67	4.49
Equipment available	8.5	35	2.98
Office hours	5.6	76	4.26
How prepared is the laboratory for its use	10.8	22	2.38
Lab capability to attend students with special needs	7.9	90	7.11
Evaluations - Quizzes	4.2	54	2.27
Evaluations - Midterms	4.2	83	3.49
The security equipment is the necessary and updated	10.3	56	5.77
Enough material for all students	8.9	70	6.23
Visual aids in the laboratory	3.7	65	2.41
Clean laboratory	5	56	2.80
Waste management	9.8	87	8.53
Environmental controls	1	36	0.36
		Benefit Index	**58**

As it can be seen above, if the score of equipment availability is improved, the benefit for that performance measurement will increase and the overall benefit index for the chemistry laboratory will also increase.

4.3 Summary

In this chapter, the Benefit Assessment Methodology was applied to a product (air conditioner) and to a service (chemistry laboratory). Calculations were made to see how the benefit indexes were obtained and what could they mean for the product and service. This was done merely as a demonstration of the methodology. For more precise results, a more profound study should be made to deal with his type of product or service.

5 CONCLUSIONS AND RECOMMENDATIONS

The QFD-based methodology developed in this research enables the calculation of a benefit index. This benefit index could change the way of how to assess a product/process/service by looking at it in a different way. This methodology could enhance the way products/service/processes are designed by focusing on what customer or user really wants and needs.

Presently, there are various methods available for evaluating the impacts of products and services. Two of these assessments are LCA and Risk Assessment [27]. These two focus on the impacts of products and services and only take into consideration their effect on human health and the environment. But what about what the product or service has to offer? Is that not important when assessing completely the product or service? The answer to this is yes. By assessing the product/service form all the aspects available a better one would be designed or improved. This Benefit Assessment methodology serves as a tool that calculates a benefit index. This index represents all the benefits a product or service has to offer. Comparing this to the functional unit in LCA, this methodology could incorporate all the benefits into one single value, instead of having one functional unit for each benefit.

LCA right now does not have this capability. It only assesses the impacts from the beginning of extracting raw materials to the end where the product is disposed. The LCA Benefit Assessment can contribute in this. It evaluates a product/service/process form the benefits point of view it has to offer.

Calculating a benefit index can be of some help when dealing with the decision-making process. The decision-making process is of vital necessity in any company, in any industry, in

any government. It is very important to have all the available information about certain idea to make the best decision involving different important aspects. LCA is a great tool but it needs to become better. It needs to incorporate other important aspects to keep up with the new challenges in the world. LCA could be thought of as a good decision maker tool. But it needs to keep evolving as time passes.

Incorporating a benefit assessment into LCA could improve greatly in decision-making. LCA calculates the impact. The benefit assessment calculates the benefit. Combining these two can provide a Benefit-to-Impact ratio. This ratio could have more meaning than simply just an impact index or a benefit index. With this type of information, people can make better decisions of whether a product or service can be redesigned or improved and, if the decision is to improve, these tools would help identify what areas are better to improve than others.

One great thing about this benefit assessment is that it incorporates what the customer or user is looking for when selecting a product or service. Using this type of information could be rewarding at the end of the design. Imagine using the voice of the customer, LCA and the benefit assessment to create a product or service that people would just love because it satisfied their needs completely.

The examples of the air conditioner and the chemistry laboratory help understand better what the methodology does. It helps identify which areas a company or an organization must improve in order to be able to satisfy the customer's needs. Improving these areas can help design a better product or service that can easily be marketed and could bring better results economically to a company or organization.

Although this methodology can provide good results, it is still in the first steps. It has room to improve. The one important thing is that it can be used depending on the subject of

study. To elaborate it, different weighting factors can be added to the one already created. Imagine certain product. By adding the benefits of manufacturing processes, material selection, marketing, and social benefits among others, a better Benefit Assessment tool can be created. Or simply adding the concept of sustainability to the tool could be of great benefit when evaluating products and services.

Another improvement might the use of other values than 0, 1, 3, and 9 when evaluating the relationship matrix. These are standard numbers adopted by the community when using the House of Quality. Creating other values can add meaning to the whole methodology and elevate it to new environments.

Another recommendation is to keep using the methodology and standardize it. By making it universal, many people could use it, whether they are using it for a product, a service, or a process. Following a set of rules and steps is easier than just start using a methodology without any set of general set of instructions.

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