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A QFD-TRIZ Hybrid Method for a Hygiene Product

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Abstract

This study examined the use of the QFD- TRIZ hybrid method in Inclusive Design. The requirements of the vulnerable groups are considered and applied to the design while redesigning the product. The effect of this method in redesigning adult diapers has been investigated with a focus on maintaining the elderly dignity and minimizing the caregivers' involvement in the nursing process to maintain respectful life for the elderly. In this paper, the product needs were identified by interviewing older adults and their caregivers. Then, the relationship between the elderly needs with their corresponding technical characteristics and the priority of these needs in the product was determined using the QFD method. The TRIZ Contradiction Matrix was used to identify engineering parameters in order to find ideas and create a new concept product design. Inclusive Design assures the manufacturer that the product is highly flexible and can be used in all consumer groups.
Keywords: Inclusive Design, Quality Function Deployment (QFD), Theory of Inventive Problem Solving (TRIZ)

1. Introduction

Two major trends have led to significant growth in Inclusive Design: First, population growth, and second, the assimilation of disabled people into society. According to the United Nations statistics, the world's population of people aged over 60 will be doubled by 2025, with a sharp rise from 542 million in 1995 to about 1.2 billion. Moreover, by 2030, more than 60 countries will host at least 2 million people over the age of 65 (Powell, 2010). In Iran also, the population aging index indicates a significant incremental trend. The predictions show that in 2015, the population of people aged over 60 will be 7% of the world's whole and by 2035 this number will reach 14.77%. It is also expected that by 2055, this number will reach 27.33 percent of the world population. According to the researches in the field of demography, the growth of the elderly population in Iran will be very remarkable from 2035 onwards (Kiani et al, 2010).

Inclusive Design is a general design approach in which designers ensure that their products and services meet the needs of users, regardless of their gender, ability, or age (Clarkson, 2015). Therefore, it can be claimed that Inclusive Design helps with enhancing the product capabilities (Luck, 2018).

Generally, considering social factors as parameters applied in designing the product, regardless of the type of product or industry, is of particular significance and has always been recognized as a limitation in researches in the domain of product and service design. Among these studies, we can refer to the articles such as "A benchmark-based method for sustainable product design" (A case study on wheelchair) by Hosseinpour et al. (2015), "A framework for sustainable product design: a hybrid fuzzy approach based on quality function deployment for the environment" (A Case Study on Transformer) by Younesi and Roghanian (2015), "Integration of green quality function deployment and fuzzy theory: a case study on green mobile phone design." by Wu and Ho (2015), "Evaluation of products at the design phase for an efficient disassembly at end-of-life" (A case study on. Jet aircraft) by Sabaghi et al. (2016), "A customization-oriented framework for the design of sustainable product/service system." (M elevator company) by Song and Sakao (2017) and so on.

The combination of QFD and TRIZ methods was used to redesign adult diapers with a focus on the social function of the product (maintaining the elders' dignity and the minimum involvement of caregivers in the nursing process in order to maintain respect for the elderly). This paper is organized into five sections: the first section includes an introduction, the second section contains a review of literature, the third section discusses the model implementation method, the fourth section includes the findings of the study, and the fifth section presents the conclusion.

2. Literature Review

New product development is usually defined as a set of activities that begins with identifying user needs and understanding market opportunities, and ends with the production, sale, and delivery of the product to the end-user. Product development is a knowledge-based activity by which the user needs are turned into the technical requirements of the product. Communication with customers and identifying their needs is a continuous and permanent action with the purpose of updating the products, and this aim is achieved by redesigning the products in reasonable periods of time. While changing the product parameters to meet a need, other features and functions of the product might be affected and weakened. Moreover, engineers can rarely claim that the best option has been selected and all possible design ideas have been considered in the design phase. Therefore, in order to overcome the aforementioned challenges in the process of product development, a combination of Quality Function Deployment (QFD) and Theory of Inventive Problem Solving (TRIZ) methods has been used.

By identifying the needs of all user groups, Inclusive Design approach leads to the creation of extensive capabilities in the product and helps to eliminate possible limitations in the product, and therefore it affects specific people's access (older adults, people with disabilities, etc.) to the product. Using the combined approach in Inclusive Design can help with identifying the new needs of vulnerable groups and turning them into product features. This is because QFD has always been a method for converting customer needs and voice into product features, and TRIZ has been used to identify potential contradictions and provide ideas to achieve practical solutions.

2.1 QFD Method

Quality Function Deployment (QFD) is a powerful tool for converting the customer's voice (qualitative needs) into engineering Characteristics (quantitative design parameters). QFD is widely used in making decisions about product design and production (Chan & Wu, 2002). This method provides an appropriate understanding of customer expectations in the process of designing and developing products, services, and processes, and it helps with satisfying their expectations by taking account of the customers' real needs (Aydarov et al, 2018). The Quality Function Deployment is able to turn customer needs into practical functions. Its whole process usually consists of four steps. The first step (customer needs planning matrix for translating customer needs into product design requirements) alone acts as a regular method and it is enough to translate the customer's voice into engineering Characteristics (Yenradee & Akkawuttiwanich, 2018). House of Quality matrix is the first and foremost building block of QFD. As shown in Figure 1, a simple example of House of Quality is a combination of "WHATs" and "HOWs”. "WHATs" consists of the customer's requirements and expectations from the product (voice of the customer) and "HOWs" expresses the way of representing the customer's expectations in the product (Park et al, 2012). At this step, while determining the relationship between customer requirements and the product technical characteristics in the relationship matrix, the kind of correlation among the product technical characteristics is also determined and indicated in the roof of the House of Quality.

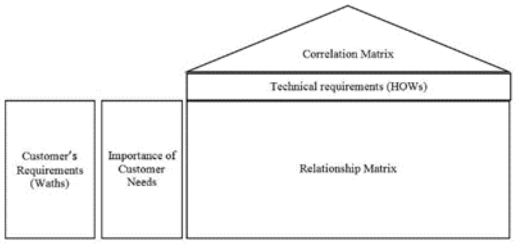

Fig. 1. House of Quality (Park et al, 2012).

The main advantage of Quality Function Deployment is focusing on customers for product innovation. This tool has been defined as an important method for improving design quality and customer satisfaction and translating customer needs into design goals (Djekic et al, 2017). The most important advantages of using QFD are as follows (Dikmen et al, 2005):

- **Accurately collecting and identifying the customer needs:** This tool provides a regular method for collecting and identifying the customer needs. Accordingly, the customer expectations are collected in the early stages and they are used to provide the appropriate design solutions.

- **Better planning:** QFD helps with tracking the customer expectations from the beginning to the end of the project, and any potential distortions can be verified in a timely manner.
- **Strengthening relationship and synchronization:** QFD requires team organization and interaction to collect the customer needs and turn them to the design goals in an accurate manner. Therefore, it directs the team to do their job using simultaneous procedures and processes.
- **Reducing uncertainty:** The initial identification of customer expectations minimizes the uncertainty as the project progresses.
- **Reducing the time for product development and redesign:** From the very beginning, the project teams are exactly aware of what they can produce

2.2 TRIZ Method

According to the principles of TRIZ method, the evolution of technical systems is not accidental, instead it is predictable based on certain rules. Since technical systems follow repetitive patterns in the long run, this pattern is regularly used to develop products. The design goal is to meet the needs of new and creative methods. Thus, the TRIZ Contradiction Matrix has been used to eliminate possible technical contradictions among product technical requirements by providing solutions based on the principles of innovation.

The contradiction arises when a designer has to choose between two different features. Technical contradictions arise when opposite states must be present in a product at the same time (Gadd, 2011). One of the most important tools in TRIZ is the Contradiction Matrix. One of the reasons for the development of systems is a flaw in their current function. Contradictory functions between system parameters usually make designers think about redesigning and modifying the current design. TRIZ seeks to resolve these contradictions by focusing on the system's contradictory functions and using innovative principles. By applying the Contradiction Matrix, these contradictions are identified and the proposed creative principles of TRIZ make it possible to solve the problem.

Creative principles in the ideation phase help engineers consider the best ideas for a new product design by examining the possible aspects. The Inventive Problem-Solving method has been recognized by many scientists as a systematic approach that offers a logical approach to provide creativity for innovation and problem solving (Ilevbare et al, 2013). As shown in Table 1, Altshuller proposed forty creative principles by examining the different inventions registered in the world. According to Altshuller, innovation is a systematic process that follows specific patterns of evolution. Recent research shows that TRIZ speeds up generating ideas for new products and services and it improves quality between 70 to 300 percent (Naveiro & Oliveira, 2018).

Table 1. Inventive principles (Naveiro & Oliveira, 2018).

N	Inventive principle	N	Inventive principle
1	Segmentation	21	Skipping
2	Extraction	22	Convert Harm into Benefit
3	Local Quality	23	Feedback
4	Asymmetry	24	Intermediary
5	Consolidation	25	Self-service
6	Universality	26	Copying
7	Nesting	27	Dispos
8	counterweight	28	Replacement of mechanical system
9	Preliminary anti-action	29	Pneumatics and hydraulics
10	Preliminary action	30	Flexible shells and thin films
11	Cushioning in Advance	31	Porous materials
12	Equipotentiality	32	Color changes
13	Do it in Reverse	33	Homogeneity
14	Spheroidality	34	Discarding and recovering
15	Dynamics	35	Transformation of Properties
16	Partial or excessive actions	36	Phase transitions
17	Another dimension	37	Thermal expansion
18	Mechanical vibration	38	Strong oxidants

Engineering parameters are the physical values involved in technical contradictions which depending on the problem should be increased, minimized, or kept at a certain value. As shown in Table 2, Altshuler has proposed technical parameters to describe the characteristics or functions of engineering systems.

2.3 Inclusive Design

The term "Inclusive Design" was first used in 1994 and it has been increasingly expanded since then. Its primary focus was on the global implications of population aging and disability for design challenges and market opportunities, and it was also an effort to create a link between design and social needs. Inclusive Design is recognized as a general design approach that its designers make sure that their products and services meet the needs of a wide range of potential users, re-

gardless of their age or ability. Inclusive Design is meant for all people in Europe and the United States. Figure 2 shows the origins of influences and ideas about Inclusive Design in both the horizontal spectrum (focusing on age and disability) and the vertical spectrum (private sector and government actions) (Clarkson & Coleman, 2015). Inclusive Design is a type of design with the aim of the maximum use of products with the most possible social function. This approach specifically focuses on the disabled and the elderly.

Table 2. Engineering parameters (Naveiro & Oliveira, 2018).

N	Engineering parameters	N	Engineering parameters
1	Weight of moving object	21	Power
2	Weight of nonmoving object	22	Waste of energy
3	Length of moving object	23	Waste of substance
4	Length of nonmoving object	24	Loss of information
5	Area of moving object	25	Waste of time
6	Area of nonmoving object	26	Amount of substance
7	Volume of moving object	27	Reliability
8	Volume of nonmoving object	28	Accuracy of measurement
9	Speed	29	Accuracy of manufacturing
10	Force	30	Harmful factors acting on object
11	Tension, pressure		
12	Shape	31	Harmful side effects
13	Stability of object	32	Manufacturability
14	Strength	33	Convenience of use
15	Durability of moving object	34	Repairability
16	Durability of nonmoving object	35	Adaptability
17	Temperature	36	Complexity of device
18	Brightness	37	Complexity of control
19	Energy spent by moving object	38	Level of automation
20	Energy spent by nonmoving object	39	Productivity

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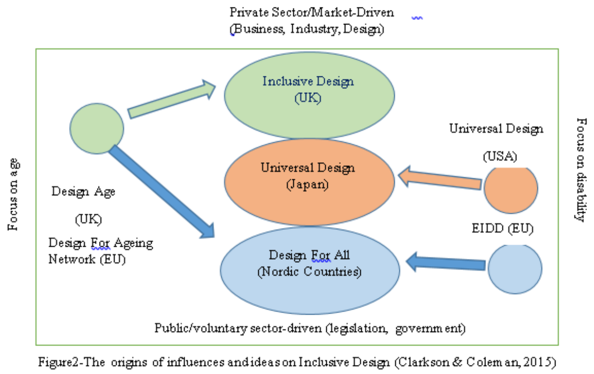


Fig. 2. The origins of influences and ideas on Inclusive Design (Clarkson & Coleman, 2015)

2.5 Inclusive Design of Hygiene Products with the Help of QFD-TRIZ: A Research Gap and an Innovation

By reviewing the literature on product design, it is clearly observed that the combination of QFD and TRIZ methods based on customer needs has been used to improve the product-service design. QFD makes it possible to translate technical characteristics into design features; however, some contradictions arise from QFD evaluation. In the correlation matrix, technical requirements that are negatively correlated with each other and are identified; they are called technical contradictions. Technical contradictions arise when opposite states must be present in a product at the same time. For example, the parameter of being automatic and cost-effective in a product is a technical contradiction, as you need to increase the level of technology in your product, but you should not increase the cost of the product in such a way that stops users from buying. Therefore, in order to strengthen the features arising from QFD, a systematic analysis based on TRIZ is performed to provide inventive solutions. In the related literature, some studies can be found about the integration of QFD and TRIZ. Specifically, you could refer to the following studies: Kim and Yoon (2012) in a study entitled "Developing a process of concept generation for new product-service systems: a QFD and TRIZ-based approach", predicted the proposed method of a carpooling service company. In the first stage, they studied the relationship between customer needs and product services and in the second stage, the relationship between service concepts and product features was identified. The most important concept at this stage is paid services. With the development of electronic payment systems, payment services will improve, but this system will make information more complex. This contradiction is resolved by the inventive principles of TRIZ. The principle of "intermediary" creativity proposes using an intermediary payment system for payment services. In “Development of an innovative conceptual design process by using Pahl and Beitz’s systematic design, TRIZ and QFD” (A case study on punching machine) by Mayda and Borklu (2014), TRIZ is used as a problem finder, a solution trigger, and a solution improver, which is an original contribution. In this research, QFD is used for converting customer needs into design parameters that are further taken as criteria in the evaluation step, which is another original contribution of this study. The applicability of the proposed model is demonstrated through a case study. The case study shows that the proposed model allows designers to find easily innovative and customer-centered solutions. In “Printer CAD: a QFD and TRIZ integrated design solution for large size open molding manufacturing” by Francia et al. (2017), the open molding technique has been discussed in order to update the current manufacturing technique in order to meet the emerging sustainable strategies. Through the integration of QFD and TRIZ, an innovative design method has been assessed for enhancing the manufacturing process by means of computer-aided engineering devices. Printer CAD is a project that aims to manage additive and subtractive techniques, applied to complex and large-scale products, by means of open-source software with an integrated module. Its aim is to enhance the CAD, CAM, and slicing for the intercommunication of 3D printer languages. In a study entitled “QFD and TRIZ integration in product development: a model for systematic optimization of engineering requirements (A case study on mortar)." by Naveiro and De Oliveira (2018), they are used to meet the most appropriate user needs and technical requirements in the design of a type of mortar, and the use of patent documents. As a result, their proposed ideas for "design of aerodynamic fins at the end of the mortar with retractability" cause longitudinal rotation, by integrating several technical requirements in the design of value-added products (increase mortar range - increase accuracy). The proposed model is generally proposed for the development of the product concept and it is also a useful method for the evolution of the modernization process. These are examples of QFD and TRIZ combinations in product design. Table 3 lists the studies conducted in the field of product design, using QFD, TRIZ, the combination of QFD and TRIZ, or the combination of each of them with any other tools. On the other hand, according to the case study in these researches, it can be observed that most of the studies have been conducted on industrial products.

In the context of designing sanitary and health care products, most of the studies are in specialized fields such as textile, chemical engineering, and so on. In this type of design, according to the designer's specialized orientation, the focus is on improving one of the product parameters. In some studies, after changing one product technical parameter, the performance of the applied changes was evaluated through the use of another tool. For example, in the study by Mendoza et al. (2019), entitled “Improving resource efficiency and environmental impacts through novel design and manufacturing of disposable baby diapers” the new design of disposable diapers for children was initially performed using petrolatum-based adhesive gels in order to reduce wastage and environmental effects.

Table 3. A review of case studies on product design

Author(s) /Year	Issue	Tools	Case study
Naveiro & de Oliviera (2018)	A model for systematic optimization of engineering requirements	QFD & TRIZ	mortar
Francia et al (2017)	Printer CAD: QFD and TRIZ integrated design solution for producing large size molds	QFD & TRIZ	Production of large molds
Wang et al (2017)	Designing a food ordering service system	QFD & TRIZ	A food ordering company in Taiwan
Tsung Ko (2017)	Modeling a hybrid design matrix for new product innovation	AD & TRIZ	Elderly Rehabilitation Equipment
Vinodh et al (2017)	Application of fuzzy quality function deployment for sustainable design of consumer electronics products	Fuzzy QFD	Auto parts
Song & Sakao (2017)	A customization-oriented framework for the design of a sustainable product/service system	AHP & TRIZ	M elevator company
Chowdhury & Quaddus (2016)	A Multi-phased QFD Based Optimization Approach to Sustainable Service Design	AHP & FQFD	health service in Bangladesh
Sabaghi et al. (2016)	Evaluation of products at the design phase for an efficient disassembly at the end-of-life stage	DOE&TOPSIS	Jet aircraft
Wu & Ho (2015)	Integration of green quality function deployment and fuzzy theory	Fuzzy Green-QFD	Mobile phone

Yu et al. (2015)	IncorporatingQFD with modularity design for improving product and its environmental compatibility at the end-of-life stage	QFDE &Modularity	Air-conditioning products
Younesi & Roghanian(2015)	A framework for sustainable product design: a hybrid fuzzy approach based on QFDE	Integrated QFDE	Transformer
Hosseinpour et al. (2015)	A benchmark-based method for sustainable product design	QFD & LCA	wheelchair
Borklu & Mayda (2014)	Development of an inventive conceptual design process, using systematic design of TRIZ and QFD	QFD & TRIZ	punching machine
Vinodh et al. (2014)	Integration of ECQFD, TRIZ, and AHP for inventive and sustainable product development	ECQFD, TRIZ‹AHP	automotive valves
Bereketli & Genevois (2013)	An integrated QFDE approach for identifying improvement strategies	Multi-aspect QFDE	hand blender
Kim & Yoon (2012)	Developing a process of concept generation for new product service systems	QFD & TRIZ	car sharing service
Yeh et al. (2011)	Integration of four-phase QFD and TRIZ in product R&D	QFD & TRIZ	notebook
Wang et al. (2010)	ECQFD & LCA based methodology for sustainable product design	ECQFD&LCA	electronics switch

Finally, by evaluating the product life cycle, the performance of this diaper was compared with the previous types. In this paper, they first tried to identify customer needs in general and in all aspects of the product using QFD and customer relationship and then using TRIZ, they tried to improve those improvable aspects of the product with the participation of experts in each section and through providing creative innovation. Therefore, the one-dimensional and scattered view of a product does not happen based on a specific specialty. Rather, it happens first by identifying the improvable points in the product and then engaging each specialty in its own respective section, in fact, a comprehensive look is taken at the design of Hygiene and health care products. Hence, it can be concluded that there are two points regarding the Inclusive Design of health products: 1- Systematic design, in a way that first the requirements and improvable points in the product are identified by means of management tools in design. Then, according to the customer's priorities and needs, the technical parameters are tested and examined by a specialist in that section. 2. Inclusive Design, in a way that vulnerable groups can be involved in the process of identifying needs.

3. Methodology

The integration of QFD and TRIZ methods makes it possible to effectively search for current market needs and the potential orientations of technological developments which lead to new products. The QFD matrix makes it possible to identify the most essential needs of users. Those needs have been evaluated in 30 seniors and their caregivers. The relationship between user needs and technical parameters was identified, ranked, and evaluated, and the principles of TRIZ's invention were used to resolve conflicts and create new concepts. QFD and TRIZ have complementary approaches and different time perspectives to search for market needs. While QFD identifies current needs, TRIZ identifies future needs through identifying patterns of technological evolution. Table 4 shows the increasing effect of QFD and TRIZ (Naveiri & Oliveira, 2018). In the following, the method of extracting and collecting data and the process of performing this work are described.

Table 4. -QFD/TRIZ synergy, *strong* ●, *medium* ○, *weak* △

Index	TRIZ	QFD
Customer satisfaction	△	●
Product quality	●	●
Profit	●	●
Market share	●	●
Innovation	●	○
Failure forecast	●	-
Support for intellectual capital	●	-
Technology perspective	●	-

3.1 Problem Statement

New challenges are emerging regarding the aging population. The product design professionals' Inclusive Design for social responsibility is new in relation to this challenge. Finding better ways for improving elderly people's relationships with their peers and their greater involvement in social activities increases their mental health and longevity. In this context, the problems of the elderly and the disabled, such as urinary incontinence, are one of the most common problems of old age that prevent the active participation of the elderly in social groups. Developing hygiene products for urinary incontinence and improving existing products can lead to the improvement of the elders' quality of life in their family relationships, social life, and work activities. Considering social factors in developing the products related to the elderly is of particular importance. However, research in the field of product design and development paid little attention to the social aspect.

The older adults' urinary incontinence problem is also problematic for their caregivers. Financial problems, as well as psychological and physical fatigue, are among the consequences for elderly caregivers. Given the above-mentioned problems, researchers believe that using high-quality products for urinary incontinence is effective in reducing the physical load for caregivers (Santini et al, 2016). Moreover, higher quality of urinary incontinence products, which reduces the presence of the caregiver, is very desirable for older adults, because in this way, their sense of dignity and self-esteem will be maintained more. This study is conducted with the aim of improving the current state of hygiene products in the country, by considering the needs of the target market, as well as the new or future technologies which can increase the products' quality.

3.2 Research Process

In the first step, the data about the needs of the product users will be collected through a semi-structured interview. There are several ways to identify customer needs. In this study, based on the research subject, a semi-structured interview will be used in an oral form. To do so, a series of default questions about the elderly problems with urinary incontinence products will be extracted from the literature and will be used as the basis of the interview. However, during the interview, the interviewees will be free to express their opinions and probably raise any number of new requirements. This type of interview is used in situations where the interviewee has special conditions or collecting information is observed during the interview process because complete information can't be obtained through standard questions. Data collection in such researches is collected using face-to-face semi-structured interviews (Santini et al, 2016).

The output of this section is the needs of the elderly in relation to adult diaper products, and 10 needs will be identified based on them. To rank the customer needs, a ranking questionnaire for customer needs will be used, and product experts will rank these 10 items by assigning a number from 1 to 10, according to their order of importance. Then the score of each need will be assigned based on the equation: "N (total number)-R(rank)". For example, rank 1 receives 9 points and rank 10 received 0 points. Figure 3 and Table 5 indicate the general characteristics of the interviewees regarding the customer needs and the product technical characteristics respectively. They determine the technical characteristics of the product:

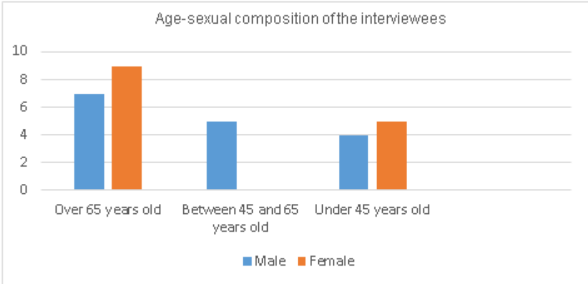


Figure3-General characteristics of the interviewees regarding the customer needs

Moreover, considering each customer need, one or more technical characteristics will be identified in the product by the product experts, and the output of this section is the product's technical characteristics. Specifying the characteristics makes it possible to identify the priority of each technical characteristic and its effect on meeting each of the needs in the QFD relationship matrix.

Table 5-General characteristics of the interviewees regarding the product technical characteristics

Connoisseur	Education	Job Title	Experience
1	Phd	Production Manager	14
2	Masters	Production Supervisor	12
3	Masters	Quality Control Manager	10
4	Masters	Production Planning Manager	8
5	Masters	Business unit expert	7
6	Bachelor	Technical expert of a production unit	4

Once the customer needs and technical characteristics of the product are identified, the QFD matrix will be formed, and the relationship matrix and the correlation matrix will be solved. At this stage, the QFD matrix will be formed according to the data related to customer needs and the product's technical characteristics. The output of this stage is the inventive ideas for resolving the identified contradictions which will ultimately lead to satisfying the needs that these contradictions arise from. At the ideation stage, the opinions of the design team will be considered and applied. The characteristics of the design team are shown in Table 6 (connoisseurs 1, 2, 3, and 4 in Tables 5 and 6 are the same).

Table 6-General Characteristics of the design team

Connoisseur	Education	Job Title	Experience
1	Phd	Production Manager	14
2	Masters	Production Supervisor	12
3	Masters	Quality Control Manager	10
4	Masters	Production Planning Manager	8
5	Masters	Nurse for the elderly	9
6	Bachelor	Nurse for the elderly	3

Finally, an evaluation will be performed according to the new concept of the product to determine whether the new concepts presented in relation to customer needs will improve the product. Innovative solutions will be represented as new technical characteristics and will be then integrated into a reference concept. At this stage, using the House of Quality relationship matrix, we will determine the impact that each of the technical characteristics (after implementing the ideas in the product) will have on customer needs (improves the need +, makes it worse -, or that need itself changes the product and formes a new idea =). If possible, we will once again generate new concepts for negative symbols through the use of TRIZ Contradiction Matrix, so that all relationships will be positive. Given the new concept of the product and through the re-evaluation of the relationship matrix, an initial evaluation of the new product will be performed. This matrix will examine the new product to check whether it has improved in meeting the customer needs (Clausing & Fey, 2004). The algorithm of the research stages is shown in Figure4.

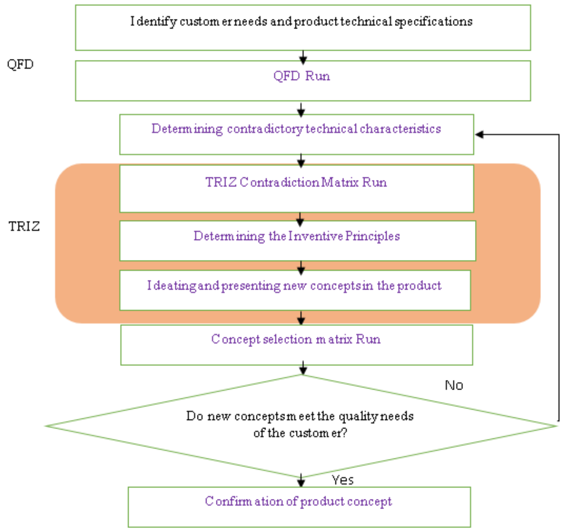


Fig. 4 Algorithm of the Research Implementation Stages

3.3 Steps of the Implementation Procedure (Case Study)

The steps for implementing the model and the input and output of each step are presented in table 7 to figure 10:

Step1. The user needs were identified through the interview with 19 seniors and 11 nurses of the older adults who could not be interviewed. Moreover, while considering each of the customer needs, one or more technical characteristics in the product were identified by product experts, and meeting the customer needs is related to these technical parameters.

Step2. The House of Quality matrix in this study consists of four main sections, including qualitative customer needs, technical and engineering requirements, relationship matrix, and finally technical correlations matrix. Its aim is to assess the type of relationship between a product's technical requirements and the identification of negative correlations between them. The effect of each technical characteristic on the needs of each

Table7-Customer Requirements

N	Customer needs	N	Customer needs
1	High absorption	6	Ease of changing
2	Not causing skin sensitivity	7	Elasticity of the side bands
3	Not spreading the bad smell	8	Not being visible and noticeable from the clothes top
4	Variety in size	9	Reasonable price of the diaper
5	Not causing skin rash and inflammation	10	Offering hygiene cleansing packs with diaper

user is shown through the use of assigned weight, which is one of the numbers (1, 3, and 9) that show the weak, medium, and strong relationships respectively. By the implementation of QFD in the first step, the ranking of the product's technical characteristics will be performed, which will take place in the House of Quality relationship matrix, by calculating the relative weight of each technical characteristic. In the roof section of the House of Quality and with the implementation of a correlation matrix, the contradictory technical characteristics will be identified, which will be the output of the QFD matrix for the implementation of TRIZ. The + and - symbols indicate the positive and negative interactions between the product's technical characteristics respectively. The negative interaction between the two characteristics indicates that either these two characteristics cannot simultaneously exist in the product or increasing the effect of one characteristic will weaken the other.

Table8-Technical Requirements

N	Product technical Characteristics	N	Product technical Characteristics
1	The material of the absorbent layer	7	Control of changing time for a diaper
2	absorbent powder type	8	Outer layer shape
3	Air exchange in the diaper's outer layer	9	Compatibility with body anatomy
4	fragrance materials	10	Glue material used between the diaper layers
5	Design of the accompanying hygiene package	11	Use of biodegradable materials as raw materials
6	The elasticity of the sidebands	12	Multiple diaper sizes
		13	Economic design

Step 3. According to the House of Quality correlation matrix and contradictory technical characteristics, at first an engineering parameter will be determined for each of the contradictory technical characteristics according to the Contradiction Matrix. Contradiction Matrix is a 39 x 39 matrix consisting of 39 engineering parameters. One parameter is in the vertical axis that needs to be improved and the other parameter is in the horizontal axis which should not be worse; and at the intersection of this matrix, there are the innovation principles of TRIZ that are used to solve this problem (Moehrle, 2005). The output of this step is the identification of the innovation principles corresponding to each pair of contradictory technical characteristics.

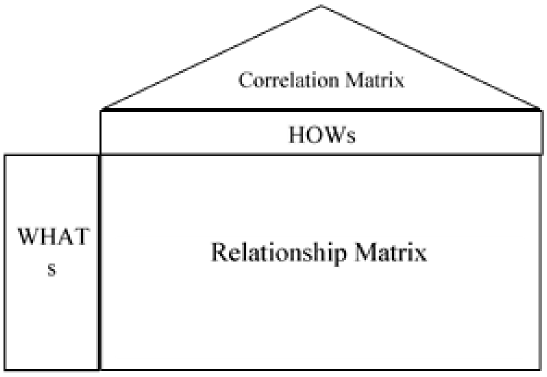
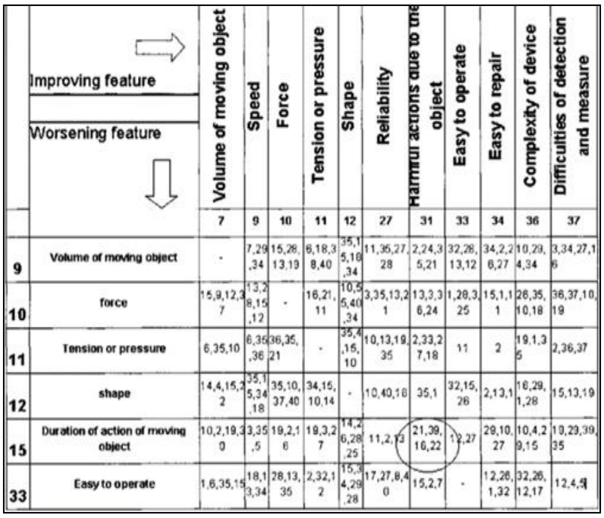


Figure 5-House of Quality (Naveiro & Oliveira, 2018)

Step4. Using the innovation principles obtained in the previous step, the design team will try to present inventive and operational ideas in the desired product, by using their own knowledge and experience. Ideation can be achieved as a team and by means of ideation methods such as brainstorming. Table 9 is a sample table:



	Improving feature → / Worsening feature ↓	Volume of moving object	Speed	Force	Tension or pressure	Shape	Reliability	Harmful actions due to the object	Easy to operate	Easy to repair	Complexity of device	Difficulties of detection and measure
		7	9	10	11	12	27	31	33	34	36	37
9	Volume of moving object	-	7,29,34	15,28,13,19	6,18,38,40	35,15,18,34	11,35,27,28	2,24,35,21	32,28,13,12	34,2,26,27	10,29,4,34	3,34,27,16
10	force	15,9,12,37	13,28,15,12	-	16,21,11	10,35,40,34	3,35,13,21	13,3,36,24	1,28,3,25	15,1,11	26,35,10,18	36,37,10,19
11	Tension or pressure	6,35,10	6,35,36	36,35,21	-	35,4,15,10	10,13,19,35	2,33,27,18	11	2	19,1,35	2,36,37
12	shape	14,4,15,22	35,15,34,18	35,10,37,40	34,15,10,14	-	10,40,16	35,1	32,15,26	2,13,1	16,29,1,28	15,13,19
15	Duration of action of moving object	10,2,19,30	3,35,5	19,2,16	19,3,27	14,26,28,25	11,2,13	21,39,16,22	12,27	29,10,27	10,4,29,15	19,29,39,35
33	Easy to operate	1,6,35,15	18,13,34	28,13,35	2,32,12	15,34,29,28	17,27,8,40	15,2,7	-	12,26,1,32	32,26,12,17	12,4,5

Figure 6-TRIZ Contradiction Matrix (Naveiro & Oliveira, 2018)

Table9 -The Idea Step

Contradictory technical characteristics	Corresponding engineering parameters	Innovation principles (Previous step output)	inventive solution (Output step 4)
X Y	✓ Efficiency ✓ power	**34**. Discarding and recovery **35**. Parameter changes	✓ changing the shape of the absorbent layer ✓ changing the type of materials

Step5. Finally, by implementing the concept selection matrix, it will be revealed which new concept will be accepted. At this stage, the concepts presented in the previous step are evaluated. The product concept is actually created by combining the solutions provided by the creative principles in the previous step. Due to the changes made conceptually and using creative principles in the product, the new product concept replaces the previous one. At this stage, any of the relationships identified in the first phase of the House of Quality (communication matrix) can be improved or weakened according to the new product concept. Relationships that improve in the new product concept receive a positive (+) sign; relationships that weaken receive a (-) sign, and relationships whose technical characteristics have been used to provide creative solutions receive a (=) sign. This means that these technical specifications have been used in the new product design. At this stage, if there is no negative relationship according to the product experts, the new product concept can be presented as a proposal. If there is a negative relationship, the previous TRIZ steps should be repeated by using the contradiction matrix and creative principles.

Table 10-Concept Selection Matrix

<table>
<tr><td></td><td colspan="3">Technical requirements</td><td rowspan="4">The concept of reference</td></tr>
<tr><td rowspan="3">customer's requirements</td><td>+</td><td>-</td><td>+</td></tr>
<tr><td>=</td><td>+</td><td>-</td></tr>
<tr><td>+</td><td>+</td><td>=</td></tr>
</table>

3.3.1 Identification of Users' Needs

Given the number of needs identified through the interviews with older adults, customer needs are ranked from 1 to 10. Then a score is assigned to each rank (based on the total number of customer needs minus the rank assigned to each need). For example, 9 points is given to rank 1, and 0 points is given to rank 10. Finally, the relative weight of each elderly need was calculated by the sum of the points related to each need in relation to the total points. Table 11 displays the ranking of customer needs.

Table 11-The relative weight of customer needs

N	Customer needs	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Total points	Relative weight
1	High absorption	9	9	7	9	7	9	50	0.19
2	Not spreading the bad smell	5	6	4	4	5	6	30	0.11
3	Variety in size	2	0	1	2	2	1	8	0.03
4	Not causing skin sensitivity	7	8	8	7	8	7	45	0.17
5	Not causing skin rash and inflammation	8	7	9	8	9	8	49	0.18
6	Ease of change	6	5	2	6	6	5	30	0.11
7	Not causing discomfort on the top diaper tape	0	4	6	0	0	0	10	0.04
8	Being economical	4	2	3	5	4	4	22	0.08
9	Not being visible and noticeable from the clothes top	3	3	5	1	3	3	18	0.07
10	Hygiene package accompanying diaper	1	1	0	3	1	2	8	0.03
								270	1

3.3.2 Identification of Product's Technical Characteristics

After determining and providing the list of customer needs, the technical and engineering specifications related to each customer need (relationship matrix columns) will be determined by the engineers of Easy Life cellulose manufacturing plant.

Then, the relationship matrix questionnaire will be used to determine the level of performance and effectiveness of each technical need in respect of the customer needs. Experts in this questionnaire will score points as follows: 0 for lack of relationship, 1 for a poor relationship, 3 for a medium relationship, and 9 for a strong relationship. Once the relationship matrix is determined, the absolute and relative weight of technical characteristics will be obtained. If the relationship between each of the qualitative demands (i) and the technical characteristics (j) are defined by d_{ij}; and a_i is the degree of importance of each qualitative demand, i.e. the absolute weight of each technical characteristic will be obtained by the following relation:

(1-1) $$W_i = \sum a_i d_{ij} \; i = 1 \dots n \; j = 1 \dots n$$

The relative weight of each technical characteristic is also calculated through the following relation:

(1-2)
$$\text{relative weight} = \frac{\text{absolute weight of each characteristic}}{\text{Sum of the technical characteristics weights}} \times 100$$

3.3.3 QFD Matrix formation

Then, by using QFD, relationship matrix, and correlation matrix in House of Quality, the relationship between customer needs and technical requirements of the product, and the internal relationship between technical requirements of product with the opinion of cellulose industry engineers are also determined. The House of Quality relationship matrix and correlation matrix is shown in Table 11 and Figure 7, respectively.

Table12-House of Quality relationship matrix

Row	Relative Weight	Customer Importance	absorbent layer material	absorbent powder type	Air exchange in the diapers outer layer	fragrance materials	Elasticity of the side bands	diaper changing time control	Economic design	Compatibility with body anatomy	Glue material used between the diaper layers	Shape of outer layer	Number of diaper sizes	Design of the hygiene pack accompanying diaper	Use of biodegradable materials as raw materials	Relative Weight
1	0.19	High absorption	9	9						1	1		3	3		0.19
2	0.11	not spreading bad smell	3	3	9	9						3				0.11
3	0.03	Variety in size					1			3			9			0.03
4	0.17	Not causing skin sensitivity	3	3	3	1		1	3	1	1				1	0.17
5	0.18	Not causing skin rash and inflammation	1	1	3		1	9						3	1	0.18
6	0.11	Ease of changing for elders					3			3						0.11
7	0.04	Not causing discomfort on the top diaper tape					3			3		9				0.04
8	0.08	Economic affordability					3		9				3	3	1	0.08
9	0.07	Not visible and noticeable from the clothes					3		3	9		9	3			0.07
10	0.03	Cleansing package accompanying diaper							3					9		0.03
	1	Technical absolute weight	2.68	2.68	2.04	1.17	1.10	1.80	1.52	1.49	0.35	1.27	1.27	1.61	0.43	19.41
		Relative weight	0.14	0.14	0.11	0.06	0.06	0.09	0.08	0.08	0.02	0.07	0.07	0.08	0.02	1
		Relative weight * 100	13.82	13.82	10.53	6.01	5.67	9.27	7.84	7.65	1.81	6.53	6.53	8.30	2.21	100

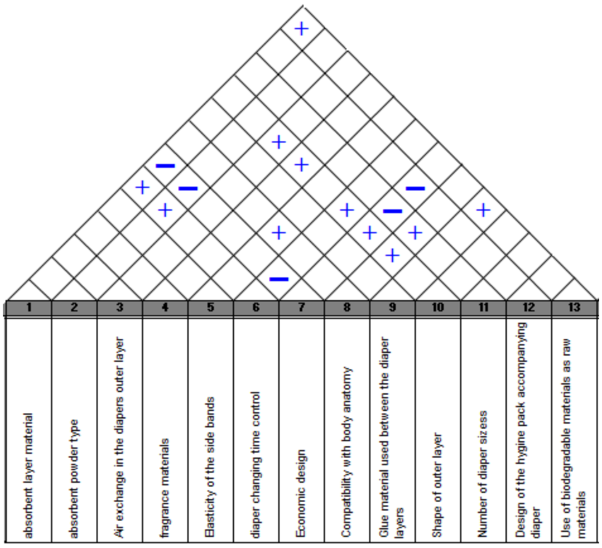


Figure7-House of quality correlation matrix

3.3.4 TRIZ as an Approach to Deal with Contradictions

The output of the correlation matrix, i.e. the technical characteristics which have negative correlations with each other, is entered as input in the Contradiction Matrix. At this stage, we first select the closest corresponding engineering parameter from the 39 TRIZ engineering parameters, found in the table for each of the contradictory technical characteristics. For example, the engineering parameter "Power" has been selected for the technical characteristics of "Absorbent Layers Material" and "Absorbent Powder Type", and the engineering parameter “Efficiency” has been selected for the technical characteristic of "Economic Design". Table 13 indicates the contradictory technical characteristics and the engineering parameters corresponding to each of these characteristics.

Table13-Correspondance of technical parameters with TRIZ engineering parameters

Product technical Characteristics	Corresponding engineering parameter	Product technical Characteristics	Corresponding engineering parameter
Improving the absorbent layers material, and absorbent powder type	✓ power	✓ ECO Design	✓ Efficiency
Controlling the time of changing diaper	✓ Accuracy of measurement	✓ ECO Design	✓ Efficiency
Design of the cleaning package accompanying product	✓ Ease of use	✓ ECO Design	✓ Efficiency

After determining the engineering parameters corresponding to each of the product's technical characteristics, the inventive principles associated with each pair of technical characteristics are identified at the intersection of the two parameters in the TRIZ Contradiction Matrix. The inventive principles in the Contradiction Matrix are located at the intersection of two engineering parameters, one of which is always known as the improving parameter and the other is known as the worsening parameter.

3.3.5 Presenting Inventive Ideas

At this stage of the TRIZ process, the project team must achieve a specific solution to the product's problem by means of creative principles. The technical contradiction solution must be in such a way that improvement in one of the product parameters does not lead to the weakening of other parameters.

Table 14-Identification of the inventive principles in the TRIZ Contradiction Matrix

Improving parameter	Weakening parameter
	Efficiency
Power	28 , 34 , 35
Accuracy of measurement	10 , 28 , 32 , 34
Ease of use	1 , 15 , 28

For instance, the technical contradiction between "power-efficiency" indicates that in order to improve the diaper's absorption power, a solution must be proposed that while improving the diaper's absorption power, the price of the product remains economical for the customer. The proposed solutions are of two types. the first group consists of solutions that do not have any negative effect on other parameters while improving one parameter. The second group consists of solutions that in addition to improving a parameter like product quality cause an increase in the product's price, but the customer is willing to pay the higher price for the higher quality and better service and it is affordable to the customer. The proposed ideas at this stage are shown in Table 15.

Table15-Presenting Inventive Ideas

Contradictory technical Characteristics		Contradictory parameters	Inventive principles	Inventive solutions
✓ Economic design	✓ Absorbent layer material ✓ Type of absorbent powder	✓ Efficiency ✓ Power	34. Discarding and recovering 35. Parameter changes or changing the physical states	Using perforated film in the inner layer of diaper Changing the type of materials used in the absorbent powder
✓ Economic design	✓ Diaper changing time	✓ Efficiency ✓ Precision	32. Color changes 28. Mechanics substitution	Using wetness indicator to show the time for changing a diaper Using a humidifier system in the diaper
✓ Economic design	✓ Hygiene pack accompanying the product	✓ Efficiency ✓ Ease of use	1. Segmentation	Designing a hygiene pack accompanying diaper including cleansing foam and pad being offered along with the main product
✓ Economic design	✓ Number of diaper sizes	✓ Efficiency ✓ Ease of use	1. Segmentation 15. Dynamics	Producing diapers with more variety of sizes than the three main sizes of small, medium, and large. Producing diapers suitable for people with extra-large sizes

3.3.6 Concept Selection Matrix

At this stage, the product concept which was created in the previous step is called "reference concept". By considering the reference concept and reviewing the relationship matrix, an attempt is taken to identify the improved or weakened relationships. In this study, the reference concept based on which the relationship matrix must be formed is an adult diaper with a double-layered absorbent core and perforated film structure. The absorbent powder used in this diaper is paper pulp-free and is only based on super absorbent powder, and a wetness indicator or moisture sensor for alerting the diaper changing time has been added to this product. It also has extra-large sizes and customers can order hygiene accessories along with the diaper. At this stage, any of the relationships identified in the first stage of the House of Quality (relationship matrix) can be improved or weakened based on the new product concept. The concept selection matrix is shown in Table 16.

Table16-Concept selection matrix

Customer needs \ Technical Characteristics of product	absorbent layer material	absorbent powder type	Air exchange in the diapers outer layer	fragrance materials	Elasticity of the side bands	diaper changing time control	Economic design	Compatibility with body anatomy	Glue material used between the diaper layers	Shape of outer layer	Number of diaper sizess	Design of the hygiene pack accompanying diaper	Use of biodegradable materials as raw materials
High absorption	=	=						+	+		+		
not spreading bad smell	+	+	+	+		+				+			
Variety in size					+			+			=		
Not causing skin sensitivity	+	+	+	+		+		+	+			+	+
Not causing skin rash and inflammation	+	+	+		+	=							+
Ease of changing for elders					+			+			+		
Not causing discomfort on the top diaper tape					+			+		+	+		
Economic affordability						-	-					+	
Not being visible and noticeable from the clothes top					+	-	+	+		-	+		
Cleansing pad accompanying diaper							+					=	

The new product concept shows that the product design has been weakened at this stage in terms of changes in “the shape of the outer layer” and "economic affordability". The shape of the outer layer has changed due to the concept of wetness indicator in the outer layer of the diaper showing the time for changing the diaper. Moreover, using a diaper moisture sensor that alerts the caregivers to the time of changing the diaper by changing color or an alarm is not suitable for the elderly. The changing time alert by creating vibration in the diaper is also not applicable for most older adults needing a nurse or a caregiver. Therefore, the humidity sensor must be able to warn the caregiver, while those around the elderly do not notice this warning. It should also be economically affordable for the customer.

The contradiction that exists at this stage stems from an improving characteristic that is called "diaper changing time control" and two weakening technical characteristics that are "diaper’s shape of outer layer "and "economic design". At this stage, the engineering parameter corresponding to the "diaper changing time control" that we intend to improve is selected to be "automation level". On the other hand, the weakened parameters are “diaper’s shape of outer layer" and "economic design". The parameters corresponding to these two characteristics are "device complexity" and "efficiency" respectively. "Automation level" is selected because the alarm sensor must be more advanced than a simple wetness indicator used in child diapers. Increasing the product’s "automation level" will lead to an increase in the "device complexity", which is a negative characteristic, and this means that to solve this technical contradiction, while increasing the level of automation, more complexity in the diaper’s outer layer must be prevented. Therefore, the project team must provide a solution that while meeting the need for "having strict control over the diaper’s changing time", does not complicate the shape of diaper’s appearance and be economically justifiable for the consumer.

Table17-Correspondance of technical parameters with TRIZ engineering parameters

product technical characteristics	Corresponding engineering parameter	product technical characteristics	Corresponding engineering parameter
Diaper’s changing time control	Automatic level	The shape of the outer layer Economic design	Device complexity Efficiency

The inventive principles associated with the parameters of "automation level", "device complexity" and "efficiency" are identified in the Contradiction Matrix according to Table 18.

Table 18-TRIZ Inventive Principles

Improving parameter	Weakening parameter	
	Efficiency	Device complexity
Automation level	5,12,26,35	10,15,24

In the following, the project team presented their ideas according to the inventive principles.

Table19-Inventive Ideas

Contradictory technical Characteristics		Contradictory parameters		Inventive principles	Inventive solution
The diaper’s changing time control	The shape of the outer layer	Device complexity	Automation level	15. dynamics 24. intermediary	Using a humidifier that has the ability to send messages on mobile software.
The diaper’s changing time control	Economic design	Efficiency	Automation level	5. Merging 26. Copying	Using a humidifier device that can be removed and reinstalled.

4. Findings

This study aimed at identifying and ranking the needs of older adults in using urinary incontinence products and improving the conceptual design of the desired product (adult diaper) by using Quality Function Deployment (QFD) and systematic innovation. By using Quality Function Deployment, needs of the elderly concerning adult diapers were identified and prioritized, and then, by using the opinions of product experts, the technical characteristics related to the needs of the elderly were identified and prioritized. By using systematic innovation methods and product expert opinions, practical ideas for improving the design of the future product were conceptually presented.

Table20-Accepted product concepts

New technical characteristics	New product concepts
1	Using a replaceable absorbent pad attached to the diaper
2	Increasing the absorbing power of diapers by using perforated film and super absorbent powders (removing the paper pulp)
3	Designing a complete hygiene package including a diaper and other necessary hygiene products with the possibility for the customers to select from different hygiene products when ordering
4	Providing diapers in extra-large sizes for specific people and as a customized product
5	Designing a reusable sensor to inform about the diaper changing time

4.1. New Accepted Product Concepts

Each new product concept creates changes in the social or economic functions of the product as described below:

Adding a replaceable absorbent pad to the diaper: Mild urinary incontinence in old adults causes the excretion of small amounts of urine which causes discomfort and the need to change the diaper. On the other hand, repetition of urinary excretion in small amounts occurs immediately after a few minutes and too much repetition very soon requires changing diapers one after another, so the cost will be very high. Nurses usually set a fixed time to change the diaper (for example, once every three hours in a nursing home), and this sometimes causes the defecation to take place a short time after the previous change. Waiting for subsequent diaper changing times can cause problems such as urinary tract infections and diaper rashes caused by urine. There are two important issues regarding mild urinary incontinence and recurrent incontinence. First, the precise control of time for changing diapers, and second, in case of mild incontinence, the diaper should not be completely changed. Cases 1 and 5 help with meeting this need.

1. **Super absorbent powders:** In the product under study, the absorbent powder is made by a combination of paper pulp and super absorbent material. Using super absorbent materials and removing the paper pulp would be better economically and environmentally, and also for the function of the absorbent layer.
2. **The possibility of ordering a hygiene pack along with the diaper:** Using hygiene products for personal cleaning is necessary for people with urinary incontinence. Some seniors who live in their own homes, and even elderly caregivers in nursing homes, have a problem and face difficulty in providing a complete package of diapers and accompanying hygiene products, and they can't order the supplies they need or different combinations of them together in one try. Creating this opportunity for the elderly can be very rewarding. The hygiene package accompanying the diaper can include a set of hygiene products needed by the elderly that can be ordered by the customer, including products such as sanitary pads for cleaning the body, hygiene cleansing foam, diaper bag, etc. Providing this opportunity is a type of service that will be created through the company's marketing website.
3. **Extra-large size:** Usually the older adults and the people with disability, or those who are hospitalized in the long run, become overweight and compared to their peers, have more problems with urinary incontinence. Customized production of special sizes of diapers for these people, while meeting this customer need, will also be economically justified for the manufacturer.
4. **Biosensors:** Usually the cost of urinary incontinence includes the costs of caregiving and buying the diaper, hiring a nurse, and medical expenses. Urinary tract infections, as the most common bacterial infection, need significant health care. Moreover, skin rashes and dermatitis, and diseases caused by not changing the diaper in a timely manner are some instances of urinary incontinence medical and health problems. In addition, urinary incontinence reduces the independence of old people and causes limitations for the elderly's social life which will negatively affect their quality of life. The problem of urinary incontinence makes them feel embarrassed and lose their self-esteem. The incontinence diaper with sensors that can tell the exact time for changing the diaper increases the caregiving

quality and it is also very desirable for maintaining the dignity of the elderly because it reduces the presence of a third party and also reduces the caregivers' repeated checkings on the diaper. Also, the fact that these sensors are not disposable will have an economic justification for the manufacturer and will not increase the price of the product for the consumer.

4.2. Suggestions for Further (Applied) Research

It is suggested that the research and development unit of Easy Life Company should produce the prototype of this diaper following a process of a feasibility study and cost-benefit estimation and if successful, it should start the mass-production of the new product.

4.3. Directions for Further Research

For future research, it is suggested other idea generation methods should be used to develop the product concept. Moreover, the use of value engineering technique and function analysis and its combination with the article model can help to make the design tools more systematic and comprehensive.

5. Conclusion

Given the demographic issues and the growing trend in population aging in the world and in our country, the elderly problems and issues have become more important today. As we move forward, issues related to the young population of the society, such as unemployment, marriage, etc., are replaced by issues related to the elderly population, such as retirement, different types of insurance, hygiene care for the elderly, and so on. Inclusive Design, through considering the product's specific functions, with regard to the needs of vulnerable groups such as the elderly and the disabled leads to a comprehensive design at the initial stage of design and it assures the manufacturer that the product is flexible enough to be used in all consumer groups. In this study, the TRIZ Contradiction Matrix was used for innovation and the generation of ideas, and the QFD method was used for information and data analysis. Using these two instruments can be helpful in generating new concepts in designing useful products, because through QFD method, first of all, we can identify the product technical characteristics which are related to customer needs, then we can focus on the most important ones, and purposefully avoid wasting time and money in the project process. Second, using TRIZ and the tools including Contradiction Matrix and the forty principles of the invention provides a mental framework for participants in the ideation phase to benefit from the experiences of the previous inventions.

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