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Applying TRIZ Principles to Construct Creative Universal Design

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Abstract

To promote daily-used products that could be easily used and accessed by all people or at least most of the people, Universal Design (UD), or Inclusive Design, initiatives have been studied and proposed by many researches over last few decades. However, a holistic and systematic approach that considers UD principles throughout its whole product developmental process is necessitated in order to ensure that UD initiatives are fully built into the product itself and versatile and innovative product concept development is also fully explored, resulting in truly benefiting the users.

This research proposed a TRIZ-based innovative product design process that incorporates UD principles. This newly formed methodology started with describing the problem, encountered during the product design and development, in terms of UD principles. The problem statement was then formulated by a 3-step inventive problem solving procedure. Contradiction Matrix of TRIZ was employed to identify proper inventive principles that could serve as resolutions, leading to improved or new product concepts. Finally, a case study was conducted to demonstrate how this creative design process works. Study result shows that this method can help identify the core of the problem and locate the improved product concepts rapidly, resulting in generating more creative resolutions.

Keywords: Product Design and Development, TRIZ, Universal Design.

1. Introduction

Nowadays Taiwan society is facing the trend of increasing aging population and declining birthrate. While accompanying by growing of minority groups, the government and enterprises started to pay attention to the social welfare and relevant issues, resulting in promoting more proper design concepts and products (Preiser and Ostroff, 2001; Duncan, 2007). Among of them, Universal Design (UD) advocated in recent years has been paid the most attention to. UD initiatives take the viewpoint of humanity to design products that emphasizing truly fulfilling the needs by all persons with all ages and abilities. It conforms to the way people pursuing modern lifestyle and interacting with and caring about each other. UD has been well established for quite some time in major countries, such as, America, Europe, and Japan. Among these countries, best practices of UD application can be found from product strategies of companies as well as curriculum in design education (Preiser and Ostroff, 2001). In Taiwan, more and more researches concerning UD are gradually getting more attention. Most of them are focusing on product design and applicability for minority groups. However, research shows that only few Taiwanese companies are applying UD into their product design and development process. UD initiatives deserve more attention by the companies to address the issues mentioned above (Huang, 2005). In general, UD principles are offering more extensive ideas or concepts. It is normally not easy

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to implement them to develop the desired products throughout the product design and development process. Therefore, there is a need to enhance or improve UD with a systematic method such that more specific and concrete resolution can be provided. TRIZ or Theory of Inventive Problem Solving is a perfect tool to help provide creative solutions effectively. TRIZ is employed to come out suitable resolutions, when there is any problem that encounters conflicts or contradictions. Though TRIZ has been introduced to Taiwan for some time and many practical applications can be found in either industries or academia, it is still not popular. Fail to make users easy understanding and using TRIZ is probably the main reason.

This research intended to construct an enhanced universal design approach that integrates both UD and TRIZ principles. This approach will help develop concrete and solid product concept throughout the product design and development with creative and systematic problem solving procedure. With this enhanced approach and personal experiences, product designer or engineer can easily generate more overall and versatile resolutions, resulting in innovative products. In addition, it should help streamline the product development process and conquer the difficulties occurred from the product design, when the approach is applied at the early stage of the product design and development. Since the comprehensive aspects of product development are considered, the developed products can then meet diverse and highly competitive market demand of today.

2. Literature Review

2.1 Introduction to Universal Design

Ronald L. Mace coined the terminology, Universal Design, as early as in mid-1980s (Mace, 1985). Its philosophy is to make all products be accessed by all people, with or without disabilities, fairly and freely, while the products are still maintained their esthetic design and market value. Firstly originated from focusing on improving daily living environment of the disabilities, UD addressed the design issue for a barrier-free environment and initiated accessible environmental design. Later it further expended its scope to promoting better usable and accessible products for all persons with all ages and abilities, resulting in the most recommended UD concepts nowadays.

The critical timing for the UD concepts to be formed is because Americans with Disabilities Act (ADA) passed in America in 1990 (Story et al., 1998; Duncan, 2007). The ADA law is meant to ensure equal opportunity and rights of disabled persons in employment, housing, education, and access to public services (US Department of Justice, 2005). Though conforming to regulations, lots of products and services are not taking people with all ages and abilities into account such that obstacles and inconveniences are still very common in our daily life. In view of this, Mace in 1988 proposed that 'Universal design is the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design.' (Story et al., 1998; Duncan, 2007) Based on this philosophy, seven universal design principles and their corresponding guidelines were cooperatively developed by a team of researchers, including architects, industrial designers, engineers, and environmental design researchers, at the Center for Universal Design and introduced in 1997 (The Center of Universal Design, 1997; Story et al., 2003). The intention of constructing universal design principles and guidelines was to provide suitable and broader common design principles to fulfill promoting universal design philosophy. The principles and guidelines were also employed to assess whether UD conformance is met or not and can serve as a guide to offer design direction at the design stage (The Center of Universal Design, 1997, Story et al., 2003). The seven UD principles are showed in Table 1.

Although the designs can be evaluated by the original seven principles of UD and their guidelines to determine how well they met, the principles principally focused on usability, the marketability of the designs was not considered. By embracing the seven principles of Universal Design, Tripod Design, a Japanese design company led by Mr. Satoshi Nakagawa, proposed three supplementary principles (as shown in Table 2) that take a product's marketability into account and developed a systematic approach, called Product Performance Program (PPP), to evaluate objectively UD performance of a design (Nakagawa, 2006).

Table 1. Seven principles of universal design (The Center of Universal Design, 1997)

1. Equitable Use	The design is useful and marketable to people with diverse abilities.
2. Flexibility in Use	The design accommodates a wide range of individual preferences and abilities.
3. Simple and Intuitive Use	Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.
4. Perceptible Information	The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
5. Tolerance for Error	The design minimizes hazards and the adverse consequences of accidental or unintended actions.
6. Low Physical Effort	The design can be used efficiently and comfortably and with a minimum of fatigue.
7. Size and Space for Approach and Use	Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility.

Table 2. Three supplementary principles of universal design (Nakagawa, 2006)

Supp. 1. Attention to Product Durability and Production Economics	The design with appropriate price is durable and easy to maintain.
Supp. 2. Attention to Product Quality and Aesthetics	The design is comfortable and aesthetic, commits to satisfactory quality and can use materials effectively.
Supp. 3. Attention to People's Health and the Natural Environment	The design is harmless to human and friendly to the environment and can promote recyclables and reusability.

This research applied both original seven principles and three supplementary principles of UD as the fundamentals to construct a systematic and innovative product design and development process for helping develop the universally usable products.

2.2 Introduction to TRIZ

TRIZ, introduced by Genrich Altshuller, is a systematic and creative approach to reach innovative results by resolving contradictions of problems. The very basis of this systematic inventing problem solving approach was to extract patent inventors' problem solving knowledge to enhance TRIZ practitioner's domain knowledge and inventing problem solving skills (Terninko et al, 1998; Altshuller, 1999; Busov et al, 1999). In addition, the knowledge was classified and induced to enable all scientific and technological fields applying the similar problem solving method. TRIZ puts emphasis on reaching invention and innovation by following systematic steps and procedures and consulting accumulated inventing knowledge of past generations, instead of searching for solutions randomly. In addition, Altshuller (1999) realized that people, constraining to their domain knowledge and tending to look for solution ineffectively by simply employing trial-and-error approach, are normally unable to apply the best practices of problem solving skills and knowledge in different fields to locate the most desired and suitable solutions. To avoid traps and obstacles along the problem solving process, an innovative inventing theory, is necessary. TRIZ is exactly the problem solving theory to address these issues.

Although TRIZ consists of many tools and techniques, such as, 40 Principles, Su-field Analysis, ARIZ, Contradiction Matrix, and Patterns of Evolution, the main problem solving tools focus on contradiction and ideation (Terninko et al, 1998; Ideation International Inc., 1999; Mann, 2007). Altshuller divided the contradictions encountered during the invention process into Physical Contradiction and Technical Contradiction (Terninko et al, 1998; Altshuller, 1999; Ideation International Inc., 1999; Gadd, 2002; Mann, 2007). In Physical Contradiction, while making a decision the same parameter of a system has to be increase and reduce at the same time in order to achieve different purposes. To eliminate the contradictions, Separation Principles are provided by TRIZ. In Technical Contradiction, when improving a parameter, another parameter may be worsened in the system. To resolve the contradictions, a Contradiction Matrix is provided by TRIZ. The Contradiction Matrix was made up by 39 Engineering Parameters and 40 Innovative Principles. While 39 Engineering Parameters help to identify the contradictions between improved and worsened parameters, 40 Innovative Principles help to direct the resolutions to the contradictions. From the extensive literature search, the extremely valuable Contradiction Matrix is the most widely employed tool in TRIZ and considered to be the suitable problem solving tool to help enhance the UD principles to generate the solid and concrete resolutions.

2.3 Product Design and Development by Incorporating UD and TRIZ Initiatives

Universal design initiates can have influences on companies both directly and in-directly. The direct influences are improving product, promoting corporate image, reducing total cost of product development, and developing new commercial interest and emerging product, while the in-direct influences are expending market share, and advocating the community responsibility of the enterprises, etc. Although the user-centered universal design does pay attention to marketable issue, commercial niche and profits are still the keys to attract to most of the companies in order to make the product realization possible. UD as a kind of design philosophy should take versatile aspects into consideration during the product design and development in order to truly fulfill both universally usable requirements and commercially interests. TRIZ is a perfect tool to help address these issues. The main idea of TRIZ is to point out the contradictions of problem and then search for potential resolutions to attack contradictions. It can facilitate exploring problem-solving methods. By applying TRIZ to help resolve problems in the initial stages of design process, it not just can prevent the mistakes occurred later, but also can improve the product development efficiency. TRIZ can help provide solution directions during the product design development and it can facilitate identifying actual reasons to resolve the technological problems (Ulrich & Eppinger, 2006).

Concept generation, concerning brief description of technology, work principle, and product form, is one of the crucial parts in the whole product design and development. It is normally describing how the product to meet customer demand and be used by most users. Essentially, it is in accordance with the concept of Universal Design. It is believed that a sound product concept plays a major role to determine to which extent a product can satisfy customers and whether or not a product can be succeed in the marketplace. Although a good concept is not necessary a guarantee to lead to product success, a bad one is definitely a commercial disaster. Concept development is fairly cheaper and faster to produce, by comparing with other activities in the product design and development process. Good product concepts through the intensive search of the concept generation process can normally enhance the confidence of the development team, since all the potential alternatives have been explored in this field (Ulrich & Eppinger, 2006).

In order to avoid the possibility of failing to locate any good product concepts or introduce more competitive products, all of the potential product concepts have to be explored and reviewed in the early stages of the product design and development. To help launch a product to the marketplace timely and successfully, proper evaluation and assessment on product is necessary. Product Performance Program (PPP) is an assessment tool in the UD field to help evaluate UD performance of a product (Nakagawa, 2006). PPP, based on the seven principles of, is constructed to objectively assess and evaluate UD performance of a product via consumer's point of view. PPP is employed in this research to assess the real case studies.

To help address these issues, TRIZ can be employed to help on concept generation. It is apparent that it should not only consider consumer's demand, but also need to prevent any problems that would take place in the product development process. And it has further shown that TRIZ is closely bound up with UD in the product design and development process.

3.A Proposed Approach to Construct Creative Universal Design

The intention of Universal Design is to develop barrier-free products that are cost-effective and marketable. However, in order to fulfill UD initiatives, it is normally facing more restrictions during the product design and development, resulting in less creative design. To address this issue, a systematic innovation approach was constructed to integrate both UD and TRIZ. With this TRIZ-based approach, the resolution is not just universally usable, but also creative and concrete. This approach also utilized PPP, which was a user-centered validation system, to objectively assess how well the design achieves UD requirements.

The creative product design and development process accommodating both UD and TRIZ principles is described as follows: firstly, the approach starts with product assessment by using PPP. Design problems or issues can be identified. The problems are stated in terms of the seven principles and three supplementary principles of UD. The problems are then formulated by a three-step for solving an inventive problem procedure, introduced by Shulyak (1997). The formulation is to analyze the product in order to determine characteristics that need to be improved. The process is guided by completing the Form F-1 (Shulyak, 1997). In addition, the formulation will help identify potential contradictions from the characteristics that need to be improved. Form F-2 can help complete this process (Shulyak, 1997).

Based on the formulated problem statement, the Contradiction Matrix of TRIZ is applied to locate the suggested inventive principles that can resolve the contradictions from the characteristics to be improved. If the contradictions cannot be easily determined, the most frequently suggested principles against each characteristic is then recommended as the potential concept solutions (Liu, 2001). After finding the inventive solutions offered by TRIZ, re-design directions of the product can be developed. Finally, PPP is employed again to verify whether the UD values of the re-designs are improved. PPP evaluation results can be represented by either numeric value or radar diagram (Nakagawa, 2006). The framework of the proposed Creative Universal Design is depicted in Figure 1.

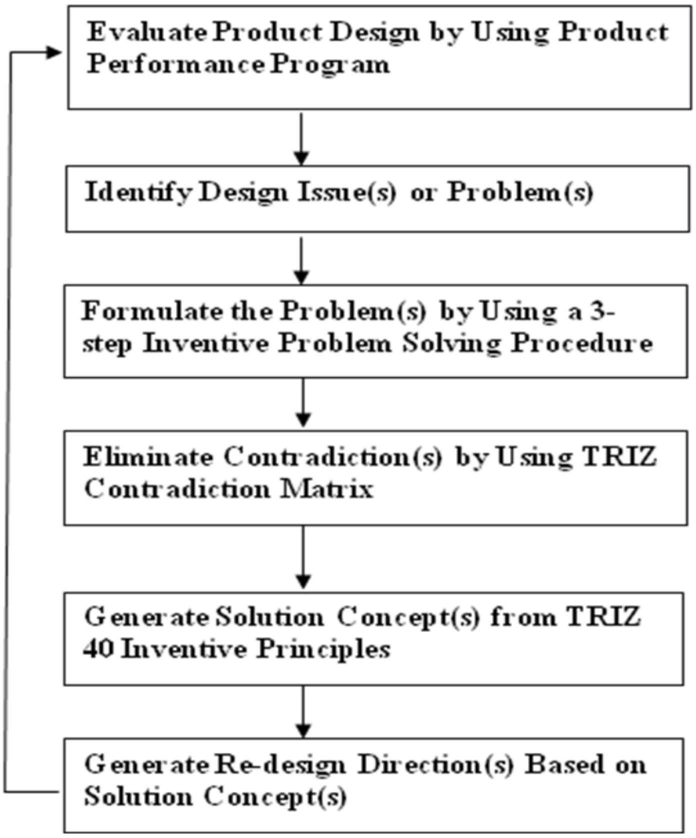

Figure 1. Framework of creative universal design

The PPP system employed by this research is not just for validating UD requirements of the design, but also for improving the UD conformance of the design. To this end, PPP evaluation is carried out twice for comparison before and after the design improvement. The first PPP evaluation is conducted prior to the improvement to identify problematic issues of the original design. The problem-solving skill described above can then be applied to deal with the problems. The second one is taking place after the improvement to assess the re-design or enhanced design. Two PPP results represented by radar diagrams can be compared side by side to validate the degree of UD achievement. To ensure the credibility of this research, all participants who enrolled in this research to conduct UD evaluation were experts or practitioners in UD field in Taiwan. By following the proposed TRIZ-based Universal Design approach, a commercially available toothbrush was chosen to demonstrate the feasibility of the approach.

4.Results and Discussion

By following the steps from the proposed approach, twelve gender balanced participates were recruited to perform PPP evaluation for the chosen toothbrush, which was a commercially available product in the marketplace. The evaluation result, represented by radar diagram, is shown in Figure 2. The lower average scores of Supplementary Principles 1 and 3 from Figure 2 indicate that these two items were the targets for improving the toothbrush design. The evaluation also stated problems in terms of the original seven principles and three supplementary principles of UD and their corresponding guidelines. Three key issues were identified; they were Principle One, Supplementary Principles One and Three. The complete statement is shown in Appendix 8.1.

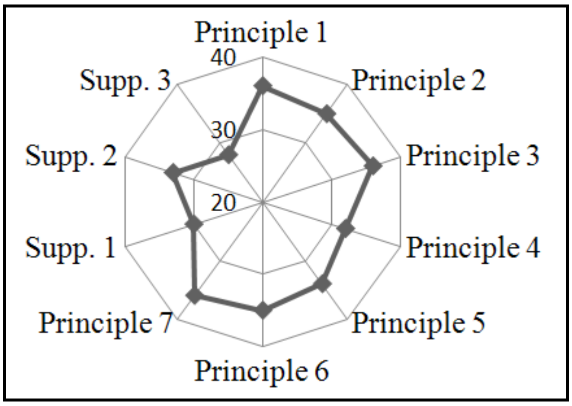

Figure 2. PPP evaluation of toothbrush (prior to the improvement)

The identified problems were then analyzed to determine which characteristic that needs to be improved, by completing Form F-1. Three characteristics to be improved were identified as: (1) equitable use for all users is not possible, (2) bristles of the toothbrush are not durable, and (3) the toothbrush is not durable and is not easily to be maintained. The complete formulation of the characteristics to be improved is shown in Appendix 8.2. After determining the characteristics to be improved, the contradictions with respect to the characteristics were identified by completing Form F-2. The complete formulation of contradictions is shown in Appendix 8.3.

To resolve the contradictions, which were no conflicts in this case, the most frequently used Engineering Characteristics were employed to locate the potential resolutions. By looking over the 39 Engineering Parameters from TRIZ, parameters 35, 34, and 26 were considered to be the most appropriate for the identified problems. The desired inventive principles (01, 35, & 35) were then determined based on the chosen parameters. The suggested inventive principles from TRIZ were provided as design directions to improve the original toothbrush. They were: re-design the size and form of the toothbrush, make the brush to be replaceable and durable, and re-design the toothbrush with improved material, form, and function to be easily adjusted. The characteristics needed to be improved and their potential resolutions are shown in Table 3.

Table 3. The potential solutions for the toothbrush to be improved

Characteristic to be Improved	39 Engineering Parameters	40 Inventive Principles	Design Direction
(1) Equitable use for all users is not possible	#35 Adaptability	#35 Transformation of properties	Re-design the size and form of the toothbrush
(2) Bristles of the toothbrush are not durable	#34 Reparability	#01 Segmentation	1. Make the brush to be replaceable and durable 2. Increase the number of the bristles
(3) The toothbrush is not durable and is not easy to maintain	#26 Amount of substance	#35 Transformation of properties	Re-design the toothbrush with improved material, form, and function to be easily adjusted

In addition to ascertaining the design concepts, the suggested design had to be verified by performing the PPP evaluation again to see whether UD principles are conformed or not. The evaluation was carried out by the same group of participants recruited. The evaluation result after the design improvement is shown in Figure 3. The figure shows that Supplementary Principles 1 and 3 were improved, after re-designing the toothbrush based on the suggested design concepts. By comparing the PPP average scores between the original design and re-design, the PPP result for the toothbrush prior to improvement was 335 and the one for improved design was 340. The higher average score for the latter one indicates that the suggested design resolutions did improve the toothbrush with better UD conformance.

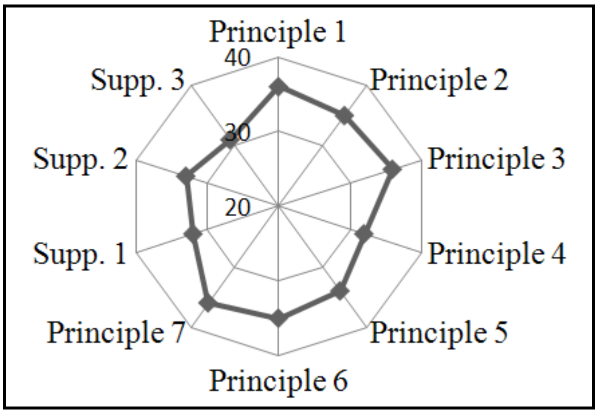

Figure 3. PPP evaluation of toothbrush (after the improvement)

By applying this newly developed innovative design approach, it is found that appearance, function, and usability of a product are not just the mere factors to be considered for design improvement. Versatile aspects need to be taken into account in order to truly reach the most desired and profound design for accommodating wider range of users with all abilities and ages in various environments. The toothbrush chosen in this research is the most familiarly daily dental cleaning tool. With the advance of toothbrush design nowadays, the regular toothbrush is considered a mature design on the market. Therefore, this research found no significant differences between prior to and after the design improvements. It is still encouraging to look into the problems with different perspectives, which may reach breakthrough and inventive resolutions to fully fulfill the satisfaction of the users.

5.Conclusions

This research intended to construct a creative Universal Design process that incorporates both UD and TRIZ principles and was manifested the feasibility of this research results by a case study. It was found that the proposed approach incorporating TRIZ could strengthen the UD principles to provide more concrete and creative solutions. In addition, the validation results from PPP evaluation system, which is employed for the comparisons prior to and after the improvement, further proved that the approach is feasible. This research also showed that both UD and TRIZ principles could work alongside to come out more creative and inventive solutions that conform to UD requirements without the need to make trade-offs.

With respect to the practical application of the newly developed approach, young designers, less experienced product planners, and students can use this approach as a guide to familiarize themselves with UD principles and concepts systematically. It can also further help them reach the creative and inventive design with UD compliance. As for experienced designers and product planners, this TRIZ-based systematic innovative approach can help break the barriers from past design practices and experiences and provide new insights and perspectives, resulting in creative, exciting, and challenging designs. This holistic and systematic approach can also help them ensure that UD requirements are fully incorporated into every aspect while conducting product design and development.

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8.Appendices

8.1 Table for Problem Statement of the Toothbrush

Principle	Guideline	Problem Statement
1	1a. All potential users could use this product in essentially the same way, regardless of differences in their abilities.	Not all potential users could use this product.
	1b. Potential users could use this product without feeling segregated or stigmatized because of differences in personal capabilities.	Yes
	1c. Potential users of this product have access to all features of privacy, security, and safety, regardless of personal capabilities.	No
	1d. This product appeals to all potential users.	No
2	2a. Every potential user can find at least one way to use this product effectively.	Yes
	2b. This product can be used with either the right or left hand alone.	Yes
	2c. This product facilitates (or does not require) user accuracy and precision.	Yes
	2d. This product can be used at whatever pace (quickly or slowly) the user prefers.	Yes
3	3a. This product is as simple and straightforward as it can be.	Yes
	3b. An untrained person could use this product without instructions.	Yes
	3c. Any potential user can understand the language used in this product.	No
	3d. The most important features of this product are the most obvious.	Yes
	3e. This product provides feedback to the user.	Yes
4	4a. This product can be used without hearing.	Yes
	4b. This product can be used without sight.	Yes
	4c. The features of this product can be clearly described in words (e.g., in instruction manuals or on telephone help lines).	Yes
	4d. This product can be used by persons who use assistive devices (e.g., eyeglasses, hearing aids, sign language, or service animals).	Yes
5	5a. Product features are arranged according to their importance.	Yes
	5b. This product draws the user's attention to errors or hazards.	Yes
	5c. If the user makes a mistake with this product, it won't cause damage or injure the user.	Yes
	5d. This product prompts the user to pay attention during critical tasks.	Yes
6	6a. This product can be used comfortably (e.g., without awkward movements or postures).	Yes

	6b. This product can be used by someone who is weak or tired.	Yes
	6c. This product can be used without repeating any motion enough to cause fatigue or pain.	Yes
	6d. This product can be used without having to rest afterward.	Yes
7	7a. It is easy for a person of any size to see all the important elements of this product from any position (e.g., standing or seated).	Yes
	7b. It is easy for a person of any size to reach all the important elements of this product from any position (e.g., standing or seated).	Yes
	7c. This product can be used by a person with hands of any size.	No
	7d. There is enough space to use this product with devices or assistance (e.g., wheelchair, oxygen tank, or service animal).	Yes
Supp. 1	This product is durable under various conditions.	Brush is not durable
	The price of the product is accorded with its performance and quality.	Yes
	The maintenance cost is reasonable.	Yes
	The maintenance is easy and after-sale service is provided.	No. Toothbrush is normally disposed after its end-of-life.
Supp. 2	The product is equipped with desired function and esthetic form and is comfortable to use.	Yes
	The quality of the product can fully meet user's need.	Yes
	The product can flexibly apply the property of the material.	Yes
Supp. 3	The product uses toxic material.	Some
	The product uses environmentally friendly material.	Some
	The product can be reused, recycled, and re-generated.	Some

8.2 Formulation of a Characteristic to be Improved (F1)

1. State the name of the Technical System: Toothbrush
2. Define the goal of the Technical System. The system is designed to: Clean the mouth and teeth and prevent dental problem and bad breath.
3. List main elements of the Technical System and their functions: The commercially available toothbrush.
4. Describe the operation of the Technical System: Apply some toothpaste to the brush of the toothbrush first and then operate the toothbrush by hand to clean the tooth and gum.
5. Determine the characteristics that should be improved or eliminated:
   (1) Equitable use for all users is not possible.
   (2) Bristles of the toothbrush are not durable.
   (3) The toothbrush is not durable and is not easy to maintain.

8.3 Formulation of Technical Contradiction (F2)

State the positive Characteristic that should be improved:

(1) Equitable use for all users is not possible.
(2) Bristles of the toothbrush are not durable.
(3) The toothbrush is not durable and is not easy to maintain.

a. The Characteristic is?
   (1) Clean tooth and remove bacterium.
   (2) Easy to use and understand.
   (3) Can be used freely.
b. State a conventional means to improve the Characteristic?
   (1) Adjust the handle length of the toothbrush.
   (2) Improve the brush material.

(3) Replace the toothbrush regularly.

c. State a Characteristic that is getting worse under conditions in line b? No

d. Formulate Technical Contradiction as follows: If the Characteristic (a) is improved by? Then the following Characteristic will get worse? No

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