Proposing a Practical Method for Conceptual Design Process in New Product Development: Medical Glasses as a Case Study

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ABSTRACT

Nowadays, improving the quality of products, reducing cost and meeting customer's requirements are necessary to shorten the time of new product development (NPD). NPD is used to describe the complete process of bringing a new product to market and conceptual design process (CDP) is at its early stage and has mostly changed from passive respond to aggressive one. Thus, this study proposed a practical method for CDP in NPD through three phases as Converting customers' requirements to product specifications, Generating and selecting of concepts and Testing and finalizing the concepts by using some different management-engineering techniques. Firstly, this paper tried to prioritize customer's requirements related to product by AHP (Analytic Hierarchy Process) and convert them to engineering parameters of TRIZ (Theory of Inventive Problem Solving) in order to define the inventive principals. Next, based on QFD (Quality Function Deployment), we measured the weight values of inventive principals. Finally, as FMEA (Failure Mode and Effect Analysis) can analyze the weight values and reduce the sequential risk, then final conceptual design was generated. At the end, a medical glasses was used as a case study of innovative design to validate the method and explain how the strategies of this research for CDP.

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1. INTRODUCTION

Creativity is known as the source of design. In fact, The nature of design is figuring out for a policy-making process in which realizes and fulfills customers' requirements. Also, during the time human's demand and requirements are increasing which it enhances the need for products and services that cause the policy-making process more difficult and complicated. To solve the complexity and difficulty of this process the concept of design process has been raised[1].

The subject New Product Development(NPD) is to explain completing the process of presenting a new product to market. According to Ulrich and Eppinger, the process of NPD includes some steps as Planning, Concept Development, System-Level Development, Detail Design, Testing and Refinement and Production Ramp-Up and the Concept Development(Conceptual Design) is second step[2]. Generally, the process of NPD can be formed as Statement of requirements, Conceptual Design, Detailing, Production Engineering and Final Product. In fact, the Conceptual Design Process(CDP) plays an essential role during NPD process as choices of production process (injection-molding, punching and forming, drawing, etc.) would be made and subsequent changes of design and production cost will be obviously influenced by the phase of conceptual design. Viewing from lifecycles of a product, the only approach for an enterprise creating an everlasting product is to shorten the periods of design and development following the trend of shortened product lifecycles in order to extend product competitiveness in an open market[3].

In this regard, this study proposes a practical conceptual design process of product through three phases as: Converting customers' requirements to engineering parameters, Generating and selecting of concepts and Testing and finalizing the concepts by using some different management-engineering techniques as AHP, TRIZ, QFD and FMEA. In this context, the study begins by a literature review and theoretical aspects as new product development and conceptual design process and some management-engineering techniques. Research methodology shows and explains three phases and will take place at second section. At the last section, a medical glasses is used as a case study of innovative design to validate the conceptual design process and the results will be discussed.

Figure 1. The Process New Product Development (Ulrich and Eppinger, 2004)

1.1. New Product Development Process

The subject New Product Development(NPD) is to explain completing the process of presenting a new product to market. NPD process in details includes some steps as Idea Generation, Idea Screening, Concept Development and Testing, Business Analysis, Beta Testing and Market Testing, Technical Implementation, Commercialization and New Product Pricing[4]. According to Ulrich and Eppinger, the process of NPD includes some steps as Planning, Concept Development, System-Level Development, Detail Design, Testing and Refinement and Production Ramp-Up as presented in "Fig. 1" and as it is shown Concept Development(Conceptual Design) is the second step[2].

1.2. Conceptual Design Process

The Conceptual Design process plays an essential role during NPD process as choices of production process (injection-molding, punching and forming, drawing, etc.) would be made. Subsequent changes of design and production cost will be obviously influenced by the phase of conceptual design. A good definition of conceptual design is the creation, exploration, and presentation of ideas. There are specific phases, or steps, of conceptual design that are needed to transfer ideas into requirements. According to Ulrich and Eppinger, the key activities of Concept Development phase is identifying customer needs, product specification, concept generation, concept selection and concept testing[2]. But these steps generally include a definition or description of the overall concept, definition of the specifications or requirements of the plan, description of what the concept is intended to achieve and a prioritized list of objectives for the concept. The bottom line is that good conceptual design will be comprised of the creation of an idea, the exploration of the intentions of an idea and the representation of an idea.

1.3. Management-Engineering Techniues

There are many design control strategies and tools such as AHP (Analytic Hierarchy Process), TRIZ (Theory of Inventive Problem Solving), QFD (Quality Function Deployment) and FMEA (Failure Mode and Effect Analysis) in which are simply useful and practical to evaluate all possible issues and avoid the time and cost waste from improper design.

1.3.1. Analytic Hirarchy Process

The Analytic Hierarchy Process (AHP) is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently[5].

1.3.2. Theory of Inventive Problem Solving

The TRIZ is a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature[6]. It was developed by the Soviet inventor and science fiction author Genrich Altshuller and his colleagues, beginning in 1946[7]. Following Altshuller's insight, the theory developed on a foundation of extensive research covering hundreds of thousands of inventions across many different fields to produce a theory which defines generalizable patterns in the nature of inventive solutions and the distinguishing characteristics of the problems that these inventions have overcome. Altshuller screened patents in order to find out what kind of contradictions were resolved or dissolved by the invention and the way this had been achieved. From this he developed a set of 40 inventive principles and later a matrix of contradictions. Rows of the matrix indicate the 39 system features that one typically wants to improve, such as speed, weight, accuracy of measurement and so on. Columns refer to typical undesired results. Each matrix cell points to principles that have been most frequently used in patents in order to resolve the contradiction.

1.3.3. Quality Function Dvevelopment

The Quality function deployment (QFD) is a method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process. QFD is designed to help planners focus on characteristics of a new or existing product or service from the viewpoints of market segments, company, or technology-development needs. The technique yields graphs and matrices. QFD helps transform customer needs (the voice of the customer [VOC]) into engineering characteristics (and appropriate test methods) for a product or service, prioritizing each product or service characteristic while simultaneously setting development targets for product or service[8].

1.3.4. Failour Mode and Effect Analysis

The failure modes and effects analysis (FMEA) is a procedure in product development and operations management for analysis of potential failure modes within a system for classification by the severity and likelihood of the failures. A successful FMEA activity helps a team to identify potential failure modes based on past experience with similar products or processes, enabling the team to design those failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs. It is widely used in manufacturing industries in various phases of the product life cycle and is now increasingly finding use in the service industry[9].

2. RESEARCH METHOD

According to the important role of CDP in NPD, this paper proposes a practical method for CDP based on management-engineering techniques by 3 phases as follows and shown in “Fig. 2”.

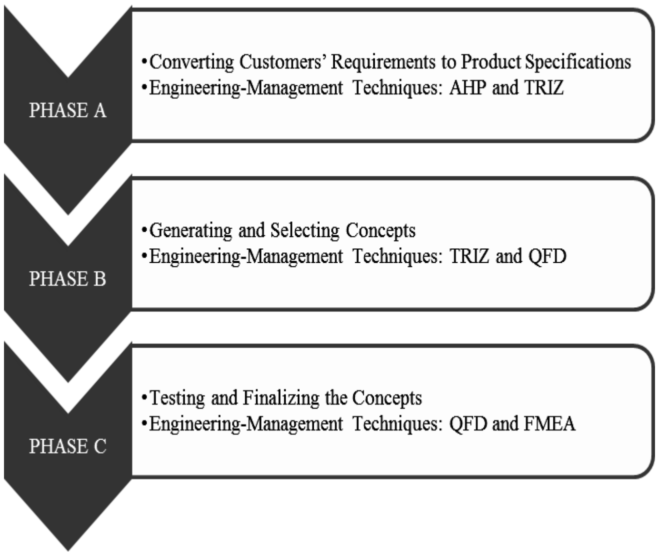

Figure 2. A practical method for CDP

2.1. Phase A: Converting customers' requirements to product specifications

The most important purpose of this phase is converting customers' requirements to product specifications through gathering customers' requirements by questionnaire and integrating AHP and TRIZ techniques. Actually after gathering the customers' requirements by questionnaire, they can be assessed and prioritized by AHP. Next, as TRIZ contains most of engineering issues through its 39 engineering parameters and in addition, customer requirements can be an essential source for them, then it can be assumed that these requirements are related to engineering parameters. Finally, after realizing engineering parameters related to requirements, they will be prioritized by AHP to select major ones.

2.2. Phase B: Generating and selecting concepts

At first, this phase is run to generate and develop relevant solutions in which are originated through TRIZ Inventive Principles. Actually, according to engineering parameters prioritized in previous phase and examining them from the matrix of contradiction, potential inventive principals related are received to find out the solution for improving the design. Next, by using the HOQ(House of Quality), one of QFD methods, the engineering parameters and the inventive principals should be placed in the most left column of engineering requirements and in the upper column of technical requirements respectively. A great number of technical requirements occur in this part which could cause a waste of time for subsequent evaluations. Furthermore, the subjective concept of engineers will place great influence on the results produced. Such results obtained will meet customer requirements and decrease the complication of subsequent evaluation on strategic design. Engineers will get some innovative ideas due to TRIZ inventive characteristics.

2.3. Phase C: Testing and finalizing the concepts

The main purpose of this phase is to evaluate and test the design strategy obtained from the second phase. Actually, it is hard to identify if failure would occur in subsequent design which may cause changes of design and FMEA is a suitable tool for verifying if the product of design could be realized on market. As the factors influencing production, speed and cost become the keys to success for enterprise's future, then it is better to avoid problems during the later develop stages in advance and decrease the risk through FMEA which is frequently used by enterprises for evaluating and testing the reliability of parts design and production process. Therefore, to test and evaluate the solutions (or the inventive principals), the results of them in HOQ should be affected by their results in FMEA. In this way, the final conceptual design will be tested and evaluated.

3. CASE STUDY

The integration of AHP, TRIZ, QFD, FMEA was proposed by this study for constructing a method for product conceptual design process. It mainly serves the purpose of discussing how design management methods raised in early phases of design influence the overall speed, cost and reliability of product development. Therefore, this study provides the example of an innovative design on medical glasses as case study to verify the effect of such method.

3.1. Phase A

3.1.1. Gathering customers' requirements

According to the market investigation and search, a questionnaire related to medical glasses was designed and distributed out among diversity of groups of customers including both sexes, different ages and sellers and so on in Tehran city(capital of Iran). The main purpose of this questionnaire was gathering and realizing customers' requirements related to disadvantages and deficiencies of current glasses. Finally, after gathering and analyzing all questionnaires, customers' requirements were classified in 3 categories such as functional group(not pressure on nose(1), not pressure on ears(2), being light(3) and economical(4)), aesthetical group(5) and durability(6).

3.1.2. Integrating the AHP and TRIZ

Here after gathering customers' requirements, they are prioritized by AHP technique through project team which ranked and prioritized requirements which are shown in table 1 including not pressure on the nose area(1) and aesthetics aspect(5) respectively. Next, project team explored the engineering parameters from TRIZ related to those two requirements. These engineering parameters weight of a stationary object, area of a stationary object, tension/pressure and shape(number of parameters 2, 6, 11 and 12 respectively) which the team prioritized them again through AHP and finally tension/pressure was chosen(table 2). Therefore, project team gathered 4 engineering parameters with respect to 2 customers' requirements and at the end tension/pressure as major parameter in conceptual design was selected.

3.2. Phase B
3.2.1. Selecting the inventive principle
According to first phase, the engineering parameter tension/pressure as the key parameter in conceptual design was chosen. In fact, the middle area of glasses causes pressure and tension on the nose and makes some change during the time and as a matter of fact its task is balancing frames to get information more clear. According to navigation and brainstorming of the team, it was decided that two parameters tension/pressure and stability are kind of contradictory to each other and thus, they play as parameters in which are shifting to improvement and deterioration respectively. With respect to matrix of contradictions of TRIZ and examining two above parameters 4 inventive extraction(2), changing the color(33), homogeneity(35) and composite materials(40) are realized. According to the team's navigation and brainstorming, the inventive principle as separation (2) is chosen as close relationship with customers' requirements and engineering parameters.

Table 1. AHP requirement evaluation form

	1	2	3	4	5	6	Geometric Average	Priority
1	1	4	3	6	2	6	3.100	0.408
2	1/4	1	1/2	1	1/3	2	0.661	0.087
3	1/3	2	1	2	1/2	2	1.050	0.138
4	1/6	1	1/2	1	1/3	1/3	0.458	0.060
5	1/2	3	2	3	1	3	1.730	0.228
6	1/6	1/2	1/2	3	1/3	1	0.589	0.078
						Total	7.588	1.00

Table 2. AHP engineering parameters evaluation form

	2	6	12	11	Geometric Average	Priority
2	1	2	1	2	1.41	0.337
6	1/2	1	1/2	1/2	0.59	0.14
12	1	2	1	1/2	1	0.24
11	1/2	2	2	1	1.19	0.24
					4.19	1.00

3.2.2. Integrating the TRIZ and QFD
In accordance with separation principle, two solutions were suggested by team as removing just pads area and adding an extensional band to the frames end (1) or removing the whole middle area and adding an extensional band to the frames end(2). In fact, an extensional band is added to balance between two frames and make glasses get information more clear which these two solutions are shown in table 3. In the next step of this phase, these solutions are prioritized through HOQ (one of QFD methods) by weighting values to them. Actually, this step shows how customers' requirements, engineering parameters(design criteria) and inventive principles(technical requirement) are related and connected to each other in which with respect to these relations all value weightings are measured that in this way the first solution as removing just pads area and adding an extensional band to the frames end is selected (table 4).

3.3. Phase C
3.3.1. Teting the solutions
The purpose of this step is to through FMEA positively prevent changes of design. In FMEA, three evaluation criteria including detection difficulty, incidence and seriousness refer to functional failure of parts and components. However, this study seeks for effects analysis towards different design methods. Therefore, it is suggested to set up other proper evaluation criteria by senior engineers. The evaluation on preliminary design can be divided into production, assembly and usability. Evaluation on Production identifies if the parts or components derived from design is easy to produce which dominates the development speed as shown in table 5. Evaluation on assembly takes cost of parts into consideration since wrong design for parts may cause damage on other valid parts. Such damage becomes a waste of cost as shown in table 6. Evaluation on usability refers to how different designs make a product easy to use as shown in table 7. After setting up new evaluation criteria, introduce the design methods derived from inventive principles to FMEA analysis form for analyzing feasibility as shown in table 8. The outcome of risk priority index clearly identifies which design can satisfy production, assembly and usability. The lower the risk priority index is, the more it satisfies the requirements raised. Then, set the lowest risk priority index as 1 and the rest accordingly.

Table 3. Requirement conversion

Customer Requirement	Design Criteria	Engineering Parameter		Inventive Principle
		Tension/Pressure	Stability of Composition	Extraction
Not Pressure on the nose	The middle area of frames	Removal of just pads area	Partially instability	Solution 1
		Removal of the whole middle area	Completely instability	Solution 2

Table 4. QFD Form

Customer Requirement \ Technical Requirement		Inventive Principle	
		Extraction	
		Solution 1	Solution 2
Not Pressure on the nose	The pads area	9	1
	The middle area	3	9
QFD weighting		12	10

Table 5. Easy to produce level(A)

Easy to produce	Phenomenon	level
Most difficult	Second processing and special treatment are needed	10
More difficult	Second processing is needed	9
Difficult	Special treatment is needed	8
Less difficult	Manual adjustment is needed	7
Middle	Both manual and automatic production lines are needed	6
Easy	Automatic production line is needed	5
Easier	More than two molds are needed	4
Easy to produce	One mold is needed	3
More easier to produce	Only a processing master is needed	2
Easiest	No processing master is needed	1

Table 6. Easy to Assemble level(A)

Easy to Assemble	Phenomenon	Level
Slightest	Destroy a product is needed before assembling or disassembling.	10
Slight	Possible damage may cause while assembling or disassembling	9
Low	Possible damage may cause while assembling or disassembling	8
Lower	More than half of parts could not be used after assembling or disassembling	7
Middle	More than one part could not be used after assembling or disassembling	6
Upper	Special equipment is needed to assemble or disassemble a product.	5
Less Higher	Auxiliary tools are needed to assemble or disassemble a product.	4
High	A professional is needed to assemble or disassemble a product	3
Higher	General staff are needed to assemble or disassemble a product.	2
Highest	All-in-one product without assembling or disassembling	1

Table 7. Easy to Useability level(A)

Usability	Phenomenon	Level
Worst	Dangerous matters create to jeopardize a user while in use.	10
More worst	Long-term use may cause discomfort of a user.	9
Worse	Improper use will cause instant damage.	8
Bad	Additional parts are needed to use a product.	7
Lower	A user feels uncomfortable due to great chances of instability	6
Middle	A user does not feel uncomfortable due to great chances of	5
Upper	A user does not feel uncomfortable due to few chances of instability	4
Easier	It is necessary to operate a product within limited space and environment.	3
Very easy	The operation of a product is not limited by space and environment but needs two or more steps to finish it.	2
Easiest	The operation of a product is not limited by space and environment and only one step is needed to finish it.	1

3.3.2. Integrating the FMEA and QFD

In this step, it is tried to make a relationship between FMEA and QFD. Actually, here after analyzing and prioritizing the solutions with respect to three evaluation criteria by FMEA, the outcome should be combined with the result which was measured by QFD in previous phase. As you can see in table 8, first and second solution got scores as 1 and 0.5 respectively, now these scores should be added to the bottom of the solutions in QFD to result the final decision about conceptual design outcome. By following this at the end, solution one which is removing just pad area and adding an extensional band to the frames end was selected (table 9).

Also, it is noticeable that this research has performed this conceptual design of medical glasses till the prototyping step and produced the prototype by rapid-prototyping machine U-Print which the product is shown in “Fig. 3”.

Table 8. FMEA analysis form

Item VS. Function	Potential Failure Mode	Potential Failure Effect	A	B	C	Risk Index	Relative Weighing
Solution 1	Partially instability	Less failures	3	3	2	18	1
Solution 2	Completely instability	High failures	2	5	10	100	0.5

Table 9. Final QFD analysis form

Customer Requirement	Technical Requirement	Inventive Principle Extraction Solution 1	Inventive Principle Extraction Solution 2
Not Pressure on the nose	The pads area	9	1
	The middle area	3	9
QFD weighting		12	10
FMEA weighting		1	0.5
Final weighting		12	5

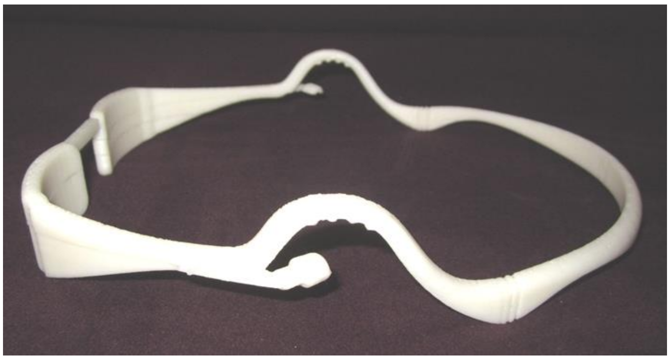

Figure 3. Manufactured prototype of medical glasses by U-print RapidPrototyping machine

4. CONCLUSION

The main purpose of this paper was proposing a practical method for conceptual design process in NPD. Actually, the integrated AHP/QFD/TRIZ/FMEA for constructing the pattern of product concept design raised by this study has been proved by case experiment as medical glasses. This method can be practically used for a design process executed in an enterprise. Such integration provides engineers an approach to convert customer’s requirements to engineering parameters by taking the advantage of AHP methodology. Then TRIZ principles are applied to provide innovative reference principles. Furthermore, the feasibility of design method is analyzed by taking the advantage of the characteristics of QFD and FMEA methodology. The above sequences not only help to clearly set up the guidelines of product design, but also help to avoid narrow thinking for products so as to further create new ideas and designs. Here the customers’ requirement was not pressure on the nose area and the engineering parameters were tension/pressure and stability. After examining and analyzing the customers’ requirement and engineering parameters, two solutions were resulted and finally only removing just pads area and adding an extensional band to the frames end was chosen which is a better choice for not having pressure on the nose.

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