A New Product Development Using Robust Design and Decision Making Process

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Abstract : This paper presents a design methodology for developing a new push scooter. A case study is done with effective planning processes to ensure the product quality under the different phases of a product design process. Parametric model based design process simulation and optimization is implemented by using ANSYS application tool. The relationship matrix and decision matrix are drawn by using several methods. The simulation results for deterministic design and robust design are compared. This entire design process phase can support the design and quality improvements for a new product development.

Key Words : Design methodology(설계방법), Push scooter(스쿠터), Deterministic design(결정론적 설계), Robust design(강건설계), Product development(제품개발)

1. Introduction

A push scooter model is shown in Figure 1. Our design team selected a scooter model to study the design processes for a new product development. Main objective of this study is to understand the design process and how to apply design techniques to a specific design problem. Figure 2 shows the flow of design process phase representing both conceptual design phase and embodiment design phase. All the steps are applied on the development of new product. Details are presented in the next sections.

Initial assumptions below are made by our design group before surveying to the customer requirements. The most important features of push scooter are listed below.

- Easy to drive or handling
- Quick to fold and efficient brakes
- Purpose of use 'sports'
- Range 'small and medium'
- Non-motorized scooter considered

Finally, Deterministic Design and Robust Design methods are applied to derive the robust solution on the selected alternative configuration. Applications of those methods are mentioned in the previous paper.[1] Technological innovation and the design process are presented more details in.[2] Different phases of a product design process require different tools that comply with their

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respective purposes.[3]

2. Conceptual Design Phase

Under this phase, many questionnaires were taken into account for the customer survey. Table 1 and Figure 3 shows the bench mark data and comparison of specifications of four scooters which collected information available in our local market. A target is intended for a local market. Table 2 shows the user requirements which analyzed and quantified based on customer survey and benchmark data. Table 3 shows the mission profile for a new scooter development. Quality Function Deployment (QFD) shown in Figure 4 is applied in this study. Quality Function Deployment (QFD) is an effective planning process in a new product development and limitations of QFD are discussed in.[4] It achieves the maximum custom satisfaction through translating voices of the customer voices into voice of engineer in the house of quality. An Affinity diagram shown in Figure 5 is prepared to classify the factors affecting the performance and design requirements. The requirements are selected on the basic of customer and engineer view points.

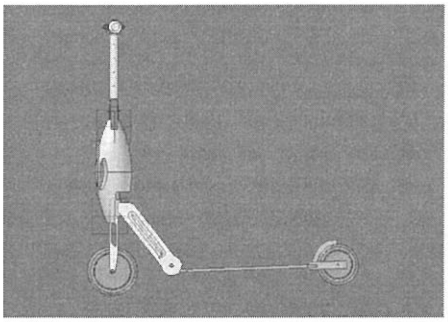

Fig. 1 Scooter Model

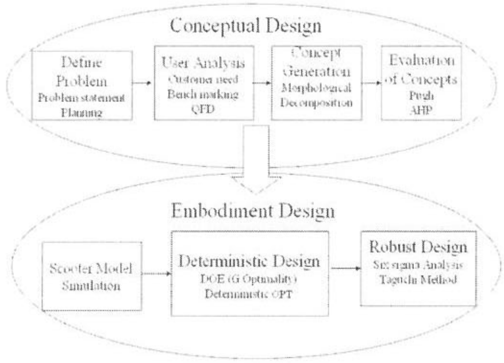

Fig. 2 Design Process Phase

Table 1 Benchmark Data

	Viza Kikit Air Push Scooter	Razor A	Titan	Go-Ped Know-Ped
Height (in)	22	23	**21.75**	33
Weight(lb)	9	**5.7**	7.5	11.3
Folded Length(in)	22	24	26	33
Folded Width(in)	8	21	4	13
Folded Height(in)	8	8.38	9.5	13
Deck Length(in)	7.25	7.31	14	33
Deck Width(in)	4	4.1	4	9
Frame	Aluminum Alloy	Aluminum	Aluminum	Steel
Folding	Yes	Yes	Yes	Yes
Handlebar Height Range(in)	22-35	23-35.25	21.75-33.25	33-38
Wheel Size-Front(in)	5.91	3.86	4.92	6
Brakes	Rear Friction Brake	Patented Rear Fender Brake	Rear Friction Brake	Front: Caliper Rear: foot brake
Max Rider Weight(lbs)	350	220	350	300

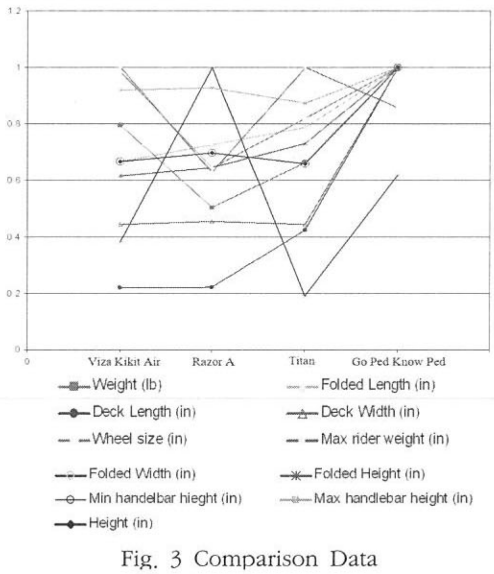

Fig. 3 Comparison Data

Table 2 Data for User Requirements

Item	User Requirements
Height (in)	27.5
Weight(lb)	6.5
Folded Length(in)	30
Folded Width(in)	8.5
Folded Height(in)	12
Deck Length(in)	24
Deck Width(in)	6.5
Frame	Aluminum Alloy
Folding	Yes
Handlebar Height Range(in)	27.5-35.5
Wheel Size-Front(in)	4.5
Brakes	Rear Friction Brake
Max Rider Weight(lbs)	220

General Characteristics
Max Weight – 220 lbs
Folded Size (L30xW8.5xH12) (in)
Unfolded Size (L24xW6.5xH27.5) (in)
Frame : Aluminum Alloy

Performance
Speed
Turning Degree (180 – 270 Deg)

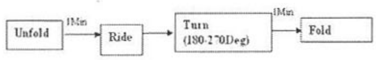

Table 3 Mission Profile

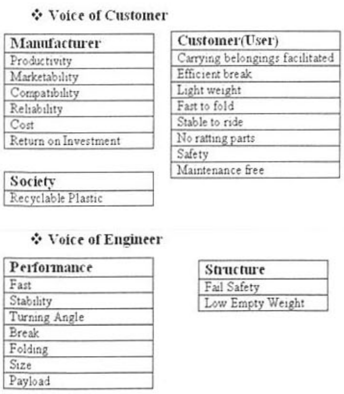

Fig. 5 Affinity Diagram

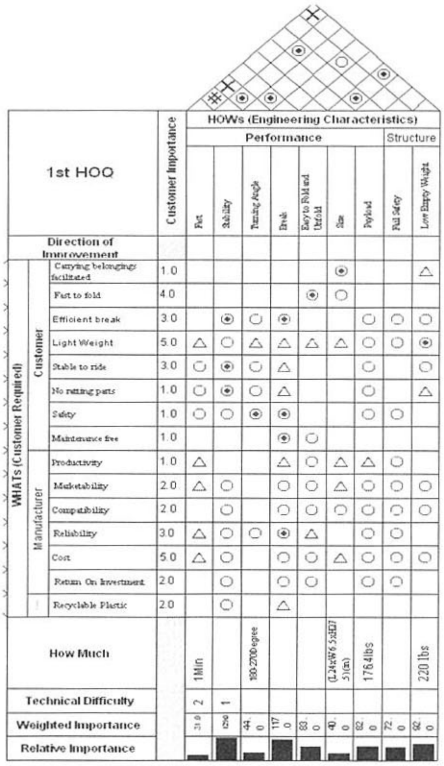

Fig. 4 QFD Chart

After developing benchmark data, QFD and Affinity Diagram, design processes for concept generation are applied. Figure 6 shows the direct decomposition of a push scooter into subassemblies. Functions of a push scooter are shown in Table 4. To consider the functional decomposition, it involves a transformation between an initial state and a desired final state. According to the assumptions, there are three main devices should be improved in order to make easier to control, achieve the sport and driving performance, quick foldable, and efficient brakes: Wheel, Frame, and Brakes system.

Table 4 Function of Scooter

Device	*Input*	*Function*	*Output*
1. Wheel	Mechanical Force Vibration	Rotation Contact with road Transfer vibration	Movement Vibration
2. Foldable Frame	Bending Mechanical	Fold the frame	Folded Frame
3. Brakes	Compression Force	Decrease Rotating wheel velocity	Friction Force Heat energy

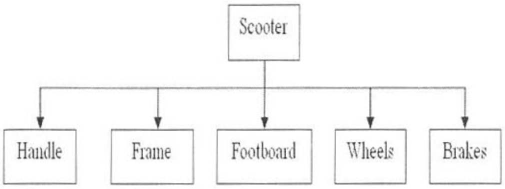

Fig. 6 Decomposition of Scooter

For concept development, it is absolutely depended on the personal and team knowledge based creativity to generate such design concepts. In this case, those concepts are generated to improve the above functional requirement and meet the assumptions. Morphological Chart shown in Table 5 is presented to arrange the functions and sub-functions in logical order, and lists the concepts in individuals.

Table 5 Morphological Chart

Sub-function	Concepts	
	A	B
1.0 Wheel		
1.1 Road contacted	Increase wheel size to 200 mm in diameter Change to use Rubber	Use plastic wheel
1.2absorb vibration	Spring with straight frame	Spring with Oscillated frame
2.0 Foldable Frame		
2.1Fold mechanism	Pull upward	Squeeze
2.2Fold position	At Main frame	At main frame and footboard connection
3.0 Brake		
3.1decrease the rotating wheel velocity	Hand brake as bicycle	Kick-brake

Table.6 Pugh's Concept Selection

Sub-function	Concepts	
	A	B
1.0 Wheel		
1.1 Road contacted	Increase wheel size to 200 mm in diameter Change to use Rubber	Use plastic wheel
1.2 Absorb vibration	Spring with straight frame	Spring with Oscillated frame
2.0 Foldable Frame		
2.1 Fold mechanism	Pull upward	Squeeze
2.2 Fold position	At Main frame	At main frame and footboard connection
3.0 Brake		
3.1 Decrease the rotating wheel velocity	Hand brake as bicycle	Kick-brake

The combining concepts from Morphological Chart are calculated for the consideration on how many number of combinations available. In this case, 32 possible combinations are found. Nevertheless, we may select only the outstanding concept of each sub-function. Concepts generated are listed in the following below. To evaluate the concepts generated, Pugh's Concept Selection shown in Table 6 and Analytic Hierarchy Process (AHP) shown in Figure 7 are applied. Table 7 presents the result of decision matrix to select a concept by using AHP.

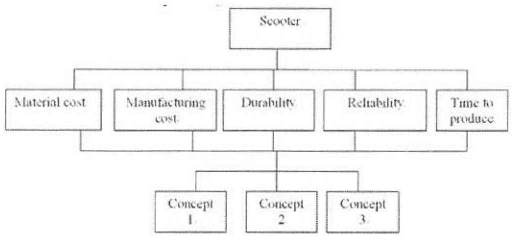

Fig. 7 Hierarchical Structure for AHP

Table 7 Decision Matrix

	Concept 1	Concept 2	Concept 3	
Material cost (Won)	4000	2500	3000	Ranking
	500.0	800.0	666.7	Reciprocal
	0.25	0.40	0.33	Fraction of total

	Concept 1	Concept 2	Concept 3	
Manufacturing cost	5000	4000	5000	Ranking
	400.0	500.0	400.00	Reciprocal
	0.30	0.38	0.30	Fraction of total

	Concept 1	Concept 2	Concept 3	
Durability	Good	Satisfactory	Very Good	Ranking
Score	7	5	8	Reciprocal
	0.35	0.25	0.40	Fraction of total

	Concept 1	Concept 2	Concept 3	
Reliability	Good	Satisfactory	Very Good	Ranking
	7	6	8	
	0.33	0.28	0.38	Fraction of total

	Concept 1	Concept 2	Concept 3	
Time to produce (hours)	3	2.5	3	Ranking
	0.35	0.29	0.35	Fraction of total

3. Embodiment Design Phase

3.1 Scooter Model Simulation

A scooter parametric model is shown in Figure 8 which modeled for design simulation and analysis. Using parametric model has an advantage for saving design time. Design constraints and apply load can be set for repetitive program simulation to get an optimum result. ANSYS[5] was used for parametric modeling, analysis of Deterministic Design and Robust Design in this study.

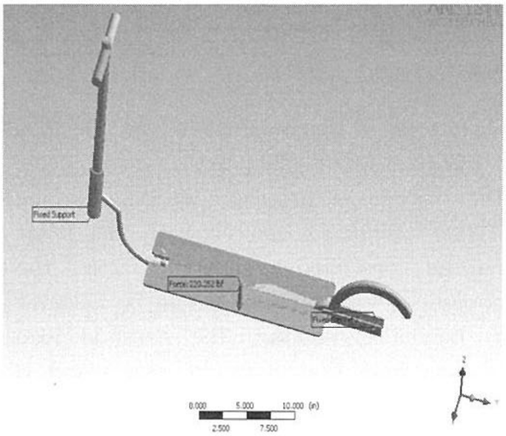

Fig. 8 Parametric Model

3.2 Deterministic Design

Figure 9 shows a flow chart of deterministic design. The Central Composite Design method was used for selecting 25 design points. Response Surfaces was constructed for objective function ($R_{adj}^2 = 0.9998$) and constraint ($R_{adj}^2 = 0.99706$).

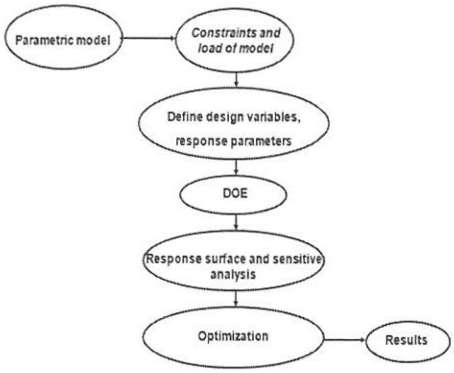

Fig. 9 Deterministic Design Flow Chart

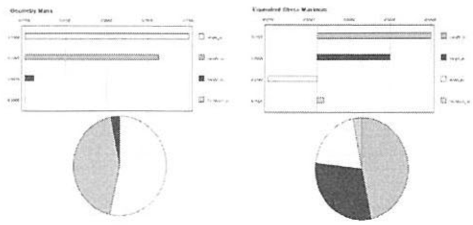

Fig. 10 Comparison on the level of sensitivity

3.2.1 Problem statement

- Objective function:
To minimize Mass (x1, x2, x3, x4)
- Constraint:

$$\sigma_{\max}(x_1, x_2, x_3, x_4) \le \frac{\sigma_y}{S}$$

- S : Safety factor for scooter for aluminum

$$\sigma_y = 40611 psi$$

- Height : Distance between scooter deck and handle bar.

Design variables are shown in Table 8. Figure 10 shows the comparison on the level of sensitivity for each design variables to the objective function and constraint. The most sensitive design variables can be chosen as noise factor for Robust Design due to the tolerance for manufacturing. However, the effect of design variables on response parameter is less. Therefore, others factors are chosen as noise factors. Table 9 shows the results of Deterministic Design. Front wheel and rear wheel have same size and same mass equal to 2.1351 lbs. From table 9, optimum mass of scooter can be obtained as 12.4315lbs.

Table 8 Design Variables and design space

	Baseline	Lower	Upper	Percent of Baseline change
Height (in) (x1)	8.00	5.62	10.44	30%
Width (in) (x2)	6.50	5.20	7.80	20%
Length (in) (x3)	24.00	19.20	28.80	20%
Thickness (in) (x4)	0.20	0.160	0.24	20%

Table 9 Result of Deterministic Design

	Screening Method	Genetic Algorithm
Height (in) (x1)	6.429	6.429
Width (in) (x2)	5.234	5.234
Length (in) (x3)	19.341	19.341
Thickness (in) (x4)	0.211	0.211
Geometry Mass (lb)	8.161	8.161
Equivalent Stress Maximum (psi)	19181	19181

3.3 Robust Design

Flow chart and definition statement for robust design are shown in Figure 11 and Figure 12.

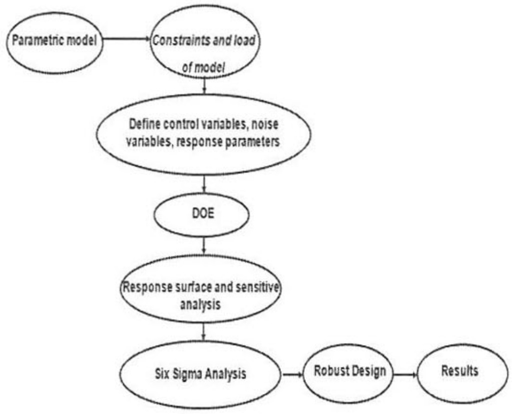

Fig. 11 Robust Design Flow Chart

In case of Deterministic Design, the load is placed at the middle point of scooter deck. The position of passenger standing on the scooter cannot be controlled so that factor can be considered as a noise factor. The position of load distribution can be assumed as normal distribution. The statistical load position from front wheel to rear wheel is 100%. From these assumptions, the load position distribution is obtained as shown in Figure 13. In addition, material density distribution can be also considered as a noise factor with Gaussian distribution shown in Figure 14.

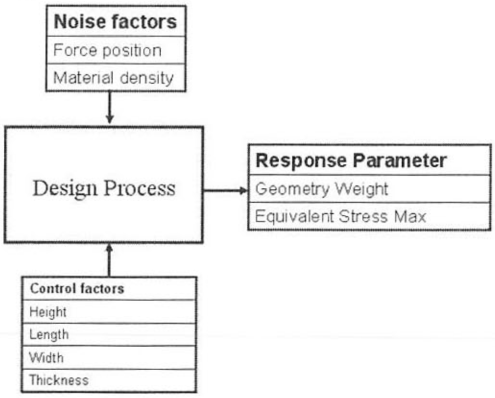

Fig.12 Definition Statement

DOE was executed by using VIF-optimal method[5] with 45 design points. For Six Sigma Analysis,[5] the sample generation is based on the Latin Hypercube Sampling (LHS)[5] technique with sample size as 80000. Figure 15 shows a response from Latin Hypercube Sampling. Robust Design is interpreted from a Six Sigma Analysis leads to an optimization problem that tries or enforce a design that satisfies the variance within 6 quality goals. Six sigma analysis will be kept as target of variation and then apply for objective function as shown in Figure 16. From table 10, optimum mass of scooter can be obtained by applying MOGA (Multi-Objective Genetic Algorithm)[5] as 12.7359 lbs.

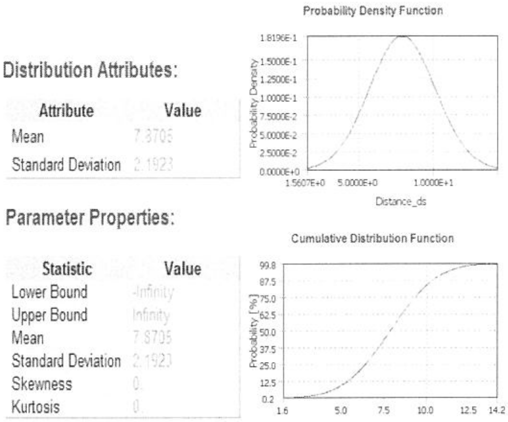

Fig.13 Noise factor(position of load)

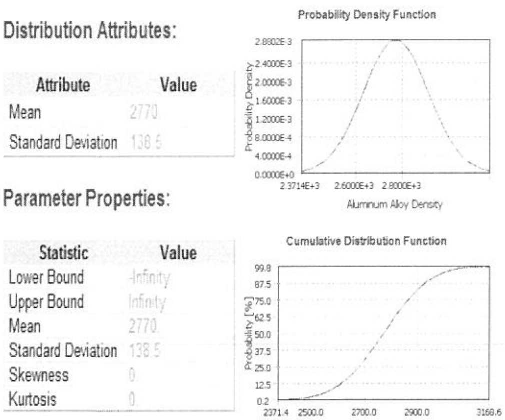

Fig.14 Noise factor(material density)

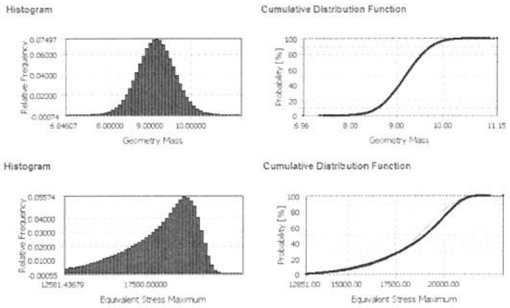

Fig.15 Response from LHS Function

Height (in) (x1)	6.200
Length (in) (x3)	5.700
Thickness (in) (x4)	0.198
Width (in) (x2)	20.670
Geometry Mass Mean (lb)	8.465
Probability that Equivalent Stress Maximum <=14578 psi	0.543

Name	Target	Desired Value
Geometry Mass Mean (SSA Sample Set 1)	-	Minimum Possible
Probability that Equivalent Stress Maximum <= 19036 (SSA Sample Set 1)	-	Maximum Possible

Fig. 16 Result from robust design

4. Conclusion

Parametric model based analysis is very efficient method. Using several different tools could give an optimal result to satisfy the new product quality improvement and required customer satisfaction. Manufacturing processes and operation of environment condition affect deeply to noise factors. Robust Design is considered noise factors. Comparing to the results between Deterministic Design and Robust Design, the results of Robust Design are more reliable.

Acknowledgement

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