2010

A Comprehensive Methodology to Generate and Select Design Ideas

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Proceedings of the 2010 Industrial Engineering Research Conference
A. Johnson and J. Miller, eds.

A Comprehensive Methodology to Generate and Select Design Ideas

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Abstract

There are many different methods for generating and selecting ideas to create a new design or improve an old one. In general, researchers tend to focus on a limited set of aspects during the design process. This paper proposes a complete methodology for creating a new design that starts from the customer needs assessment and end with the final design. The methodology was created while designing a variable message sign mounting device. The proposed methodology employs elements from existing customer assessment tools, concept generation methods, and concept selection methods. We will show the usefulness of the method with a case study and present the final design that resulted from the proposed methodology.

Keywords
Design, Concept Generation Methods, Concept Selection Methods

1. Introduction
There are many different methods for generating new ideas as well as selecting the ideas in order to create a new design or to improve an old one. In general, researchers tend to focus only in one aspect of the design process, that is, either on the concept generation method or on the concept selection method**.** Further, during the design process stages (customer needs assessment, concept generation, concept evaluation and selection, etc.), tracking these aspects, and arriving at a balance across them becomes very complicated. In order to address these issues, we propose a complete and robust methodology for creating a new design that starts from the customer needs assessment and end with the final design. The methodology was created while designing an industry sponsored variable message sign mounting (VMS) device. The proposed methodology employs elements from existing customer assessment tools, concept generation methods, and concept selection methods, and brings all under a cohesive framework. It also brings modifications to existing methods to increase robustness. The methodology flowchart is given in Figure 1. In the rest of the paper, we will show the usefulness of the method with a case study and present the final design that resulted from the proposed methodology.

2. Understanding the Customer and the System
The first step to any good design is understanding who the customers for the product are. After knowing who they are, it is important to ask them what are the features and aspects that are highly valued, in other words, what do they want and what do they need. King and Sivaloganathan [1] mention that the first stage of the design process identifies the requirements of the customers and from these customer requirements a list of product specifications is developed. In this case, a customer approached us with the requirements for their design. The customer currently sells a portable variable message sign, which provides officer and citizen safety at an accident scene or emergency situation. This full size, full matrix display can be dispatched from the back of a vehicle and set up by a single person.

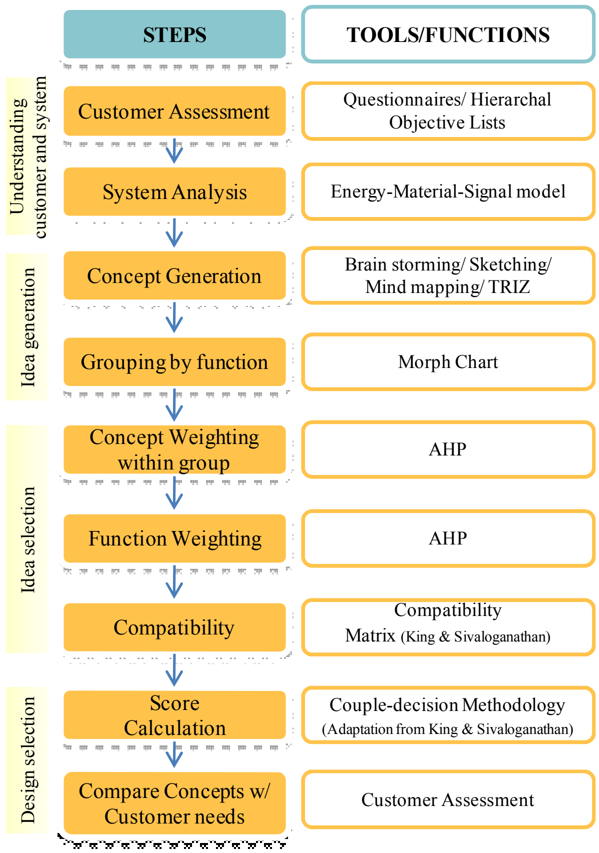

Figure 1- Proposed comprehensive methodology

The sign can quickly and easily communicate exactly what is needed using its 1, 2 or 3 lines of text with 7", 10.25", or 24" letters that are visible hundreds of yards away. The customer was looking for a new mounting device for their message sign which is called a variable message sign mounting (VMS) device. According to customer requirements, the system must have a final cost of less than $200; it must be rugged, allowing repeated set-ups and tear-downs without failing in a harsh environment. It must be able to be field installed in less than 2 minutes, by one person, in order to meet the requirement of speed when public safety is at risk. The system has to hold the message sign open as there are no provisions on the sign to do this. Finally, the collapsed mount system must fit in a police car trunk.

As recommended in our proposed methodology, first a Hierarchical Objective List was done in order to categorize the objectives, functions, and constraints. Then an Energy-Material-Signal (EMS) model was constructed in order to have a clear understanding of the problem. We created two diagrams, one representing the assembly of the device and one representing the teardown of the device. By doing this, some ideas came into mind such as inverting the steps of disassembling and moving to the car, minimizing the number of parts to disassemble, and minimizing the weight of the device.

3. Idea generation

For the idea generation we propose the use of multiple concept generation methods. For example, we started brainstorming combined with sketching. Figure 2 shows one of the sketches done while brainstorming. After generating enough ideas with the brainstorming we then used the TRIZ method to transfer the ideas into concepts and solutions. TRIZ works under the idea that a specific problem can be expressed as a general problem to which a general solution already exists. It focuses on technical contradictions which consist of solving conflicts among parameters. Figure 3 presents an example of TRIZ design suggestions for design contradictions. For more detailed information about TRIZ please refer to [2, 3].

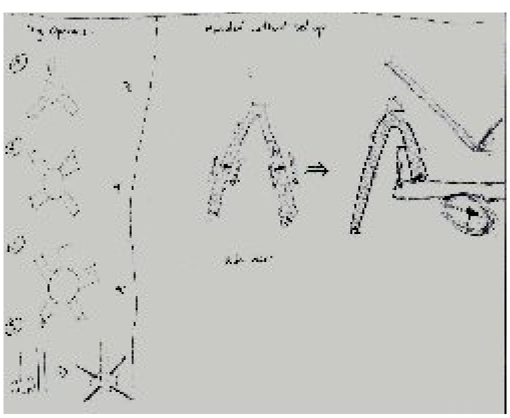

Figure 2- One of the sketches derived from brainstorming

39 productivity [Install in 2 min by 1 person]	4 length [easy to store]	IDEAS
	30 Flexible films or membranes [26]	extendable legs
	7 Nesting dolls [34]	contractable legs
	14 Spherical shapes [27]	retractable legs
	33 convenience of use [flexibility]	
	1 Segmentation [3]	extendable/retractable legs
	28 Replace a mechanical system [4]	seperated mounting connectors
	7 Nesting dolls [34]	contractable legs
	10 Preliminary action [2]	fit in trunk when assembled
	2 Weight, stationary [light]	
	28 Replace a mechanical system [4]	seperated mounting connectors
	27 Cheap disposable [13]	disposable sandbags
	15 Dynamism [6]	wheeled legs
	3 Local quality [12]	3 column/legs (tripod)
	37 complexity of control [easy to operate]	
	35 Physical or chemical properties [1]	composite materials
	27 Cheap disposable [13]	disposable sandbags
	15 durability	
	10 Preliminary action [2]	fit in trunk when assembled
	16 Partial or excessive action [16]	cheaper materials

Figure 3- TRIZ design suggestions for design contradictions

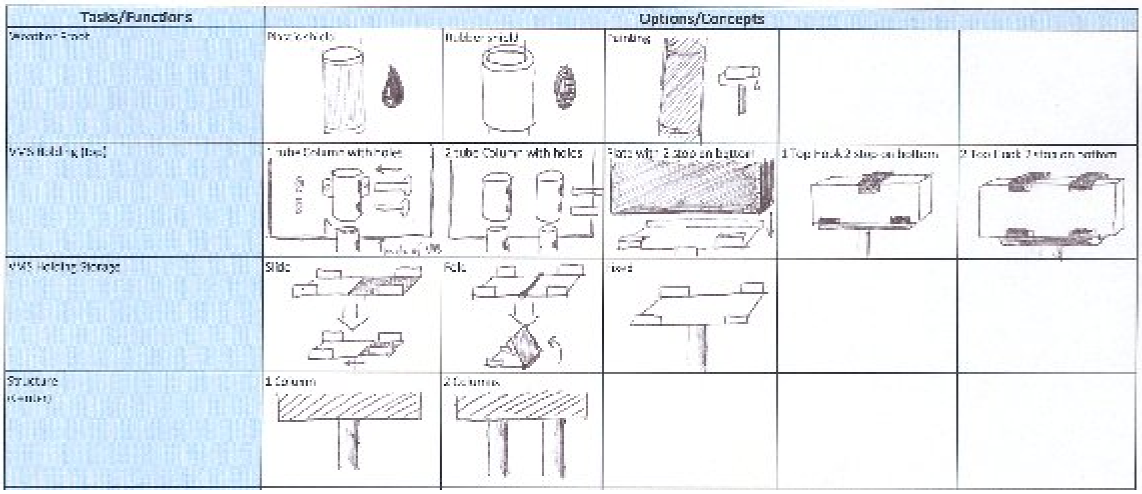

Figure 4- Part of the morph chart constructed for the VMS mounting device.

After the ideas are generated, they should be grouped by function. Some of the ideas provide similar or same function in different words. In this step, a morph chart will make the ideas into comprehensive concepts. The morph chart is an evaluation process that categories the concepts into go/no go design combinations. It's important for the chart to show the possible combinations, and avoid the impossible or infeasible combinations. Such method is a method of MECE, or "Mutually Exclusive, Completely Exhaustive" [4]. To be more precisely, this method poses MPI, or "Mutual Preference Independence". Figure 4 presents a sample of the morph chart constructed for this problem.

4. Idea Selection

As it can be seen from Figure 4, the concepts that were generated are grouped by functionality. At this moment the decision makers (DMs) play a fundamental part in what is going to be the final design. Each DM should decide how much weight to assign to each concept within a function or a group. In addition, each DM needs to assign weights to the different functions according to what each believe adds more value to the product from the customer's point of view. In our methodology we propose using the Analytical Hierarchical Process (AHP) for both stages. AHP is a pairwise comparison method that gives a magnitude on how much one alternative is preferred over another. It uses a range of numbers from 1 meaning no preference up to 9, meaning that one alternative is extremely preferred over another. For detailed information on AHP, please refer to [5-8].

Of the concepts generated, some of the concepts are compatible. However, some of them are less compatible, and some of them even are incompatible. Such compatibility problem is common, and many tools incorporate such compatibility concern [1].

We suggest a method for flexible design named the coupled decision method, which was proposed by King and Sivaloganathan [1] and is based on the Quality Function Deployment (QFD) and the house of quality. With their proposed methodology, they incorporate into the process the effect of coupled decisions (the roof of the house) which represent the interaction between different concepts. That is, if two parts are not compatible, then the idea that contains both parts is not feasible. Figure 5 presents the QFD approach proposed by King and Sivaloganathan.

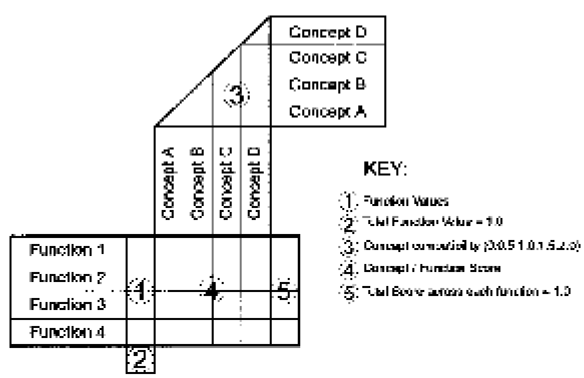

Figure 5- Matrix proposed by King and Sivaloganathan [1]

			Temperature Detection		Material composition supporting (bottom)					Material composition structure (center)					Material composition holding part (top)				
			No	Surface color (temperature)	Plastic	Carbon fiber	Aluminum	Composite	Steel	Plastic	Carbon fiber	Aluminum	Composite	Steel	Plastic	Carbon fiber	Aluminum	Composite	Steel
			C56	C55	C54	C53	C52	C51	C50	C49	C48	C47	C46	C45	C44	C43	C42	C41	C40
Weather Proof	Plastic shield	C01	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1
	Rubber shield	C02	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Painting	C03	1	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1
VMS Holding (top)	1 tube Column with holes	C04	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2 tube Column with holes	C05	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Plate with 2 stop on bottom	C06	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1 Top Hook 2 stop on bottom	C07	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2 Top Hook 2 stop on bottom	C08	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
VMS Holding Storage	Slide	C09	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Fold	C10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Fixed	C11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Structure (Center)	1 Column	C12	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2 Columns	C13	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Storage Method (Center)	Contractible	C14	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Retractable	C15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	String inside	C16	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Separated	C17	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Fixed	C18	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Height Adjustment	Pre-determined holes	C19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Screw stopper (mic)	C20	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Lock stopper (tripod)	C21	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Twist stopper (chair)	C22	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Fixed	C23	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Supporting (Bottom)	3 tripod legs	C24	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	4 pyramid legs	C25	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	5 legs	C26	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1 circular plate	C27	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 6 - Extract of the concept compatibility matrix for the VMS mounting device

By the use of a compatibility matrix, we are able to quantify the effect of coupled decisions. King and Sivaloganathan recommended assigning numbers between each pair of concepts from 0, where there is conflict between two concepts, up to 2, meaning that two concepts are highly compatible. [1]. Figure 6 presents an extract of the concept compatibility matrix (roof of the house) that we created for our problem.

5. Design Selection

In the coupled decision method proposed by King and Sivaloganathan [1], the total score of a design is calculated as the multiplication of the sum of the concept scores by the multiplication of the compatibility number for possible pairs between the concepts that form a design, as presented in Equation 1.

$$\text{Total Score} = \Sigma\,(\text{Concept/Function Score}) \times \Pi\,(\text{Concept Compatibility}) \quad (1)$$

The design with the highest score is the one considered the best design. However, King and Sivaloganathan only used the scores assigned to each concept and the compatibility number. In their QFD model, they included the weights of each function but did not use them for any calculation. In our own revision, we decided to take the function weight into account such that the total score is calculated as presented in Equation 2. Note that both, Equations 1 and 2 refer to the legend presented in Figure 5.

$$\text{Total Score} = \Sigma\,(\text{Concept/Function Score} \times \text{Function Values}) \times \Pi\,(\text{Concept Compatibility}) \quad (2)$$

There might be cases where there are numerous possible configurations, for example, 10 functions with 3 concepts each will result in 3^{10} = 59,049 possible combinations. Thus, in such cases we propose some rules in order to simplify the calculations.

- Rule #1- Calculated the total score for the top design. The top design refers to the configuration with the highest concept weights in each function.
    - If there is no compatibility issue, then this is your number 1 choice.
    - If there is a compatibility issue then look for the conflicting functions and substitute the concept of the function with the lower weight for the highest weighted concept that is compatible.

- Rule #2- Once the top design is calculated, if want to calculate several other designs in order to have a flexible design strategy, calculate other designs the following two ways:
  - For the top two or three weighted functions, substitute the current concept (which should be the highest weighted concept for the function) with the second highest weighted concept.
  - For the bottom two or three functions, substitute the current concept (which should be the highest weighted concept for the function) with the second highest weighted concept.

This method is useful for flexible designs, where the top five alternatives could be considered and perhaps a product family could be derived. In our problem we had 15 functions with 2 to 5 concepts per functions, which resulted in 135,000,000 possible designs.

Figure 7 presents the score calculation of our top alternative which we named as the "ideal configuration". Note that the numbers on the first column correspond to a concept number. They can also be seen in Figure 6 as C01, C02, etc. The second column presents the multiplication of the compatibility index of a concept with all the other concepts. For example, on the first row (Concept #2) the compatibility number presented (1) is the multiplication of the compatibility indices of 2 vs. 8, 2 vs. 10, …, 2 vs.55. Then, the number next to concept 8 is the multiplication of the compatibility indices for 8 vs. 10, 8 vs. 12, …, 8 vs. 55, and so forth. Finally, the third column includes the multiplication of the concept weight by the function weight. The total for the second column is the column product while the total for the third column is the column sum. Finally, the multiplication of this two gives the total score for this configuration.

ideal configuration:	Compatibility (product of the compatibility index between this concept and all the other concepts below this one)	Weight (Function weight * Concept weight)
2	1	0.022
8	1	0.046
10	1	0.024
12	1	0.07
14	1.5	0.023
20	1	0.008
25	1	0.077
29	1	0.026
34	1	0.095
36	1	0.059
39	1	0.007
42	1	0.021
47	1	0.03
50	1	0.078
55		0.001
Totals	1.5	0.587
	Total Score	**0.8805**

Figure 7- Score calculation for ideal configuration

Once some five to eight configurations have been defined, compare them against the initial requirements with a Customer Assessment Matrix, where a one will be placed if the design complies with the objective, function or constraint, and a zero if it does not. Figure 8 presents the Customer Assessment Matrix comparing the design alternatives with customer assessment. As seen in the figure, constraints should be the first elements to be assessed. If a design does not comply with a constraint, the rest does not matter. Similar to the constraints, the functions should also be addressed by the designs. A design that cannot do the function the customers wants might not be useful at all no matter how many extra gadgets it has. The best design is the one who complies with all functions and the most objectives without violating any constraints.

				Alternatives				
		Type	Weight	Design #1	Design #2	Design #3	Design #4	Design #5
	Less than $200	Constraint	-	1	Not feasible	1	1	1
	Installed in less than 2 minutes	Constraint	-	1		1	1	1
	Able to be installed by one person	Constraint	-	1		1	1	1
	Fit in a police car trunk	Constraint	-	1		1	1	1
	DOT regulations	Constraint	-	1		1	1	1
	Variety of assembly options	Function	-	1		1	1	1
	Hold the VMS	Function	-	1		1	1	1
1. mobility (7%)	portable (0.3)	Objective	0.021	1		1	1	1
	easy to store (0.2)	Objective	0.014	1		1	1	1
	light (0.5)	Objective	0.035	1		1	1	1
2. flexible (15%)	adjustable to different heights (1)	Objective	0.15	1		1	1	1
3. easy to operate (39%)	quick & easy set-up (0.6)	Objective	0.234	1		1	1	1
	safe (0.4)	Objective	0.156	1		1	1	1
4. durable(39%)	repeated set-up & tear downs (0.4)	Objective	0.156	1		0	1	1
	rugged/strong (0.4)	Objective	0.156	1		0	1	1
	weather proof (0.2)	Objective	0.078	1		1	1	1

Figure 8- Comparison of design alternatives with customer assessment

6. Final Design

The final design incorporates the ideal concepts in previous selection methods. Figure 9 presents a drawing of the final design. Note that the drawing is not to scale as it only represents the general ideas of the design.

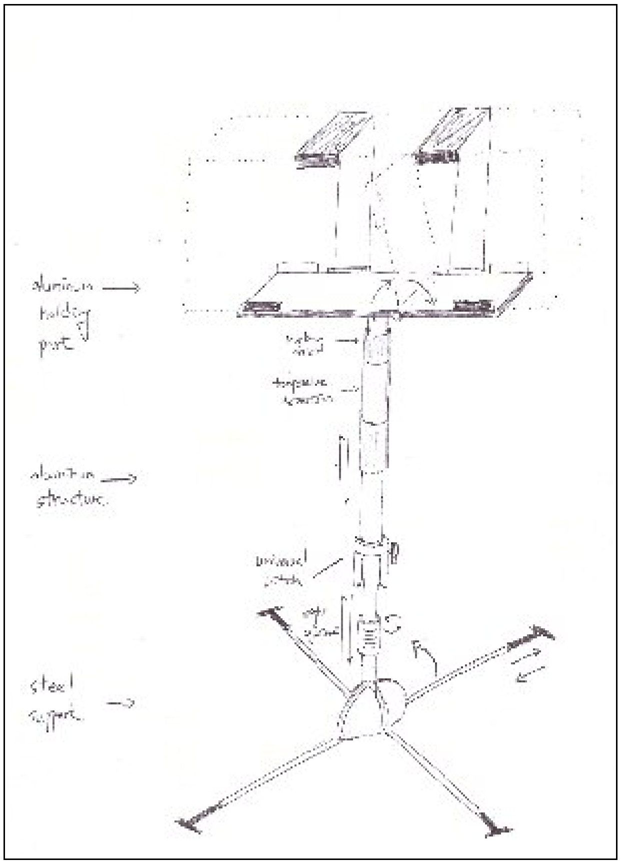

Figure 9- Final design for the VMS mounting device

The proposed design has an aluminum and foldable holding part. Such holding part is durable, lightweight, and can be installed in 2 minutes by 1 person. It is also easier to store in the trunk of various vehicles. The structure part is also made of aluminum, which is durable and light weight. The rubber shield prevents operators from slipping during assembling, and avoids them from been hurt by extremely high/low temperature. The contractible design, makes the device easy to operate, and easy to store. At the end of the structure there is a universal hitch, which fits in most vehicles, such as police car, ambulance, and trailer. Such design is very flexible, even if the vehicle is out of service. It's easy and fast to transport to another vehicle. The hitch is designed in a relative high position, which will prevent the operator from injuries, such as injury to L5/S1, and potential LBP (Low Back Pains).

The support part is made of steel. Such material provides the best durability, while the increased weight also increases the overall system stability. The extendable legs further expand such stability. The retractable 4 legs make the supporting part both stable and easy to store. The screw-type height adjustment provides additional adjustability for the height. Such design doesn't require any detachable part, thus makes the device easier to assemble.

7. Conclusion

This paper presented a proposed comprehensive methodology for a new design. The methodology starts from the customer needs assessment until the final design. It uses some functions or tools from previous existing methods as well as some modifications to other methods. We showed the usefulness of the method with a case study and presented the final design that resulted from the proposed methodology.

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