Creative Concept Convergence Tools for Use in the Product Development Stage of DFM/A

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Many engineers have embraced a rekindling of the creative thinking (Divergent Thinking) skills were prevalent during the era of Value Engineering. However, once 50 - 75 concept ideas have been developed at the concept level most engineers have few if any concept Convergence tools. Although many engineers implementing concepts of DFM/A have adopted the PUGH Concept Selection Tool, this tool should be employed in the latter stages of concept compression.

The process of screening all the ideas developed in a good Creative Concept development session will usually employ three stages. First, the ideas should be sorted into similar expressions of the same basic concept using a SORT tool. The ideas should then be COMPRESSED into a few functional categories. Lastly, the top concepts should be SELECTED from the remaining ideas using one of the two selecting tools, the Pugh Concept Selection Matrix (PUGH) or the Paired Comparison Analysis Matrix (PCA).

The mechanics of each concept compression tool will be developed and explained with a product concept convergence exercise.

ENHANCEMENT OF DIVERGENT THINKING:

In the past few years there has been considerable interest in rekindling the creative spirit of engineers, particularly in courses entitled Design for Manufacturability and Assemblability (or some variation of that theme). Engineering students are learning some divergent thinking tools in DFM/A courses, engineering creativity courses, and product realization courses. A student engineer can now generate 10 - 50 methods (mechanisms) to accomplish a product function. However, they are not being given any tools to sift through the ideas with finer and finer sorting screens until they have a small number of potential product concepts. When the engineer has only 5 - 15 concepts, then he can use a selection tool such as the PUGH concept selection matrix to choose the final product concept to bring to market. However, the existence of more than 15 potential product ideas requires the use of soft compression tools to avoid the tedious or casual application of a PUGH concept selection tool.

COMPRESSING PRODUCT CONCEPTS:

A DFM/A team that has completed a successful concept generation session will have 20 - 50 potential concepts to accomplish the function of the product. A detailed selection matrix with 10 - 20 criteria would be a very tedious task for this many ideas. Since the judgmental brain was shut down during the concept generation forum to stimulate the generation of ideas, some or many of the ideas will be novel, wacky and off beat ideas. Once the engineer has replaced the joker's cap with the mortar board of the analytical engineer, then he can begin the convergent thinking process. The analytical mind of the engineer will immediately see that some of the new

concepts will never fly in today's environmentally conscious society. Without employing the rigor of the evaluation matrix and firm criteria, the engineer can rule out certain new ideas.

CULLING is the process of separating the rotten apples from the good edible apples in the basket. Just as the image of a bad apple smacks us in the face, so too the visual image of a bad product concept will jump off the page at us. In the process of culling, the DFM/A team member uses their intuitive feelings to identify the real losers among the ideas. No formal selection criteria with metrics are used at this stage. To prevent a total wipeout of the ideas, the team is permitted to wipe out only 10% of the total ideas. After slicing off the bottom end of the pile of ideas, the team should turn to the top end of the pile to see the truly great ideas.

HITS is the convergence process of scanning for ideas that literally jump off the page at you and hit you in the mind with a loud "Winner". Hits is a soft convergence tool developed by Roger Firestein to assist clients in a Creative Problem Solving Methodology (CPS) workshop to narrow down the potential problem solutions to a reasonable number that can be evaluated in a more detailed manner with a selection matrix tool.[1] Firestein describes the characteristics of a "Hit" as: Interesting, Unique, Very Relevant, Feels Good, Concise or Jumps out at you.

If the objective of the product development process is to obtain a new and novel product, then the DFM/A team members should be encouraged to select an equal number of practical ideas and some very intriguing ideas that might work. Each member of the team should review a specific number of colored dots not greater than 25 % of the total ideas. The facilitator describes the operation of each product concept while the sketch of the product is viewed by the team. Once the concepts are all understood, each person affixes their dots to the ideas that they feel fit the criteria in their minds as hits.

If at the end of this process, there is consensus around 5 - 10 concepts, then the team should proceed directly to the detailed convergent tools. If at the end of isolating Hits there are still 20 - 50 concept ideas, then the team should employ the highlighting tool to compress those concepts identified by the hits tool into fewer more compact ideas.

HIGHLIGHTING is the systematic application of three convergent thinking tools to compress a large quantity of widely varying ideas into a few coherent idea areas. The highlighting technique which was developed by Firestein and associates[2] employs the sequential application of the Hits, Clustering, and Hot-Spots tools to methodically compress the initial ideas by focusing toward the combination of similar solutions.

The Hits tool is first used by the DFM/A team to identify those ideas that are really outstanding. The operating procedures were describe previously because it is often used alone as the only soft convergence tool.

The ideas that have not been identified by the Hits tool are placed on a wall at the other end of the room from the original ideas or placed in a box for latter reevaluation. The Clustering tool is used on the ideas, isolated by the Hits technique, in an effort to generate more effective potential solutions by clustering together several partial ideas into a totally complete solution. Before the DFM/A team members begin the actual Clustering process, the facilitator numbers ideas so that the clustering by individual team members can be more effective. Each person takes a pad of paper, reviews the ideas displayed randomly on the wall, and clusters them into a number of **related themes**. After the team members have silently gathered the ideas themselves, the facilitator guides the team in actively clustering the ideas together on the wall of the room. Together the team arrives at numerous Clusters until all the ideas are related to a group. The

initial period of silent individual clustering of ideas prevents one person from dominating the clustering process and encourages the development of multiple clustering groups.

Hot-spotting is the team created by Firestein to describe the process of developing a name for the common thread that weaves through all the ideas in a cluster. The ideas were originally pushed together because something in each team member's mind said softly that they went together. The process of clustering went much like the process of selecting a suit, shirt, and tie when silent unspoken soft criteria were used to make the selection. In product design the search for the Hot-Spot should reveal the single mechanism that expresses the shared mechanism of performing the product function being evaluated.

Once the team has arrived at a Hot-Spot description for each of the clustered groups, the number of potential product concepts should be narrowed down to 5 - 15 ideas. The initial convergence of ideas has been done with soft criteria, gut instincts, and intuitive feelings.

SELECTING PRODUCT CONCEPTS:

Once the number of product concepts have been narrowed down to a maximum of 15 ideas, a formal selection tool that utilizes firm quantifiable criteria should be used. Several different techniques of selecting ideas can be used. However, most design engineers have adopted the PUGH Concept Selection Matrix developed by Professor Stuart Pugh of Loughborough University for his students studying design.[3]

The practice of the application of the PUGH Concept Selection process by engineering students has revealed one flaw in the original work of Dr. Stuart Pugh; namely, students do not have experience verbally expressing the product evaluation criteria. This appears to be a problem that is not isolated to engineers. Isaksen, Dorval, and Treffinger[2] in their research on the Creative Problem Solving (CPS) Methodology have identified some rules for the formulation of concept evaluation criteria.

Once the DFM/A team has generated and selected some criteria for the product evaluation, all criteria should be rephrased so that they are all parallel, distinct, and abstract as described by Isaksen, Dorval and Treffinger.

PARALLEL: All criteria should be phrased such that a POSITIVE (YES) answer to the criteria means that the concept is good. "Does the product have a low assemblability rating?" and "Does the product have a high number of parts?" are not parallel criteria. A good feeling about the product would be evoked by a POSITIVE response to the first question and a NEGATIVE response to the second question. The second question should be rephrased to, "Does the product have a low number of parts?".

DISTINCT: Each question should evaluate a different aspect of the product. "Is the product safe for children to operate?" and "Are children likely to be hurt using the product?" are not distinct attributes of the product concepts to be evaluated. Only one unique criteria related to operator safety should be used in the concept evaluation matrix.

ABSTRACTNESS: Each criteria should be developed to the same level of abstractness (or detail) as every other criteria, in so far as possible. Although many engineers consider all the criteria in early concept evaluation to be "fuzzy" since they cannot quantify all of them, even the non quantifiable criteria should be at the same level of abstractness as the other criteria. The statement, "Does the processor cut celery?" is not at the same level of abstractness as "Does the processor cut vegetables?".

QUANTIFIABLE (QUALIFIABLE): * Where appropriate the criteria should be expressed in terms that can be quantified with some metric that is viewed appropriate for early

product design. The question "Does the product have good assemblability?" is too vague for most engineers to evaluate. A more quantifiable question might be, "Does the product have a low number of subassemblies?

* This fourth criteria has been added through DFM/A teaching at GMI.

The PUGH selection process proceeds as follows:[4]

1. List the product function criteria in short phrases in each row of the PUGH matrix. Typically 8-12 criteria are used at the product level including not only the functional criteria of the product , but also, aesthetic functions, manufacturability metrics, assemblability metrics, serviceability indexes, and disposal metrics should be employed where appropriate.
2. Each new product concept should be briefly described in each column of the matrix. Any number of concepts from 2 - 12 can be evaluated.
3. A product concept sketch should be developed at the same level of detail for each of the concept ideas to feed the visual side of the brain during the evaluation process.
4. **A DATUM (REFERENCE POINT, BENCHMARK)** must be selected against which each concept will be compared for each criteria. In most DFM/A practice the Datum for the initial selection process is the original product design.
5. Each concept is compared to the Datum **ONLY,** one criteria at a time until that new concept has been evaluated for all the criteria. The team then evaluates the next concept for all the criteria in the rows of the matrix. It is important to compare the new concepts only to the datum not to each other.

   A simple GO/NO-GO evaluation is made using the following criteria:

   + (Plus) = this concept is clearly better than the datum
   S (Same) = this concept is about the same as the datum
   - (Minus) = this concept is not as good as the datum
6. Only when all the concepts have been evaluated relative to the datum, should the concept ratings be tallied. The + is a + 1, the - is a - 1, and the S is a. The algebraic sum of the ratings for each concept should be entered in the row marked "Concept Rating".
7. If a single concept does not appear to clear # 1 idea in step 6, change the datum to one of the stronger concepts identified in the first evaluation and perform the PUGH analysis again. This time you will be comparing each concept, criteria by criteria, to a the New Datum. (The old datum, the original product concept should be removed completely from the matrix along with the potential concepts that rated below the original concept in the first PUGH selection analysis.)

The PUGH concept selection matrix shown in Figure 1 is the evaluation of five concepts for a new hand operated food processor. In this selection matrix, concept #4 has emerged as the most favorable concept.

IMPLEMENTATION OF TOOLS INTO DFM/A A COURSE:

The various tools for concept generation and concept analysis are learned through active practicum sessions throughout the term. Explanations of the application of each tool, the procedures for applying the tool and the direction to be taken as a result of the tool are given in tool instruction booklets. The concept generation (Divergent Thinking) and concept selection

(Convergent Thinking) tools are applied in a single 2 hour practicum workshop. In the practicum session four student teams of four students tackle a engineering problem confronting a local organization. The "warm-up" problem that is most often utilized is one that has many solutions, both logical and illogical, that can be contributed by all students. The problem statement is: "How can we prevent the beaver dams at Camp Holaka from flooding the campsites?"

When they start on the Beaver Dam Problem, the teams have already participated in some exercises to stimulate their divergent thinking. Each student team generates ideas using Classical Group Brainstorming, and Forced Random Stimulation. Each team generates 25 - 40 ideas in a 20 - 25 minute period. The concept generation activity is usually halted at this time to permit the application of the compression and selection tools within the time period. Within each team the ideas range from the violent death and destruction solutions to the calm ecologically acceptable technical solutions. Table I illustrates the range of concepts developed by one team.

The team is first asked to cull out 10 percent of the ideas that are just too wild, too dangerous, too violent or too deadly to apply in a camp situation. The team removes: C 4, TNT, Acid, Poison, Guns, Snipers and Sterilize beavers.

The team now looks for the Hits that jump out at them as interesting, intriguing, and unusual. They isolate the following concepts:

11.	retaining wall	8.	Remove trees
12	locks	28.	Remove food
15.	stilts for campground	34.	Scents of enemies
19.	Sump pump	35.	Shield trees
20.	Hydro plant		
22.	Drainage ditches		
37.	sandbags		
38.	cut trees for dike		
39.	cement wall		

They clustered these into four themes:

I	Lowering Water Level	(18, 19, 20, 22,)
II	Eliminating food	(8, 28, 34, 35,)
III	Separating camp from water	(12, 15, 37, 38, 39,)

In the interest of time the practicum facilitator provided each team with a set of criteria for evaluating their final concepts using the PUGH Concept Selection matrix. The criteria used for the beaver problem are:

Costs less than $100
Requires little maintenance
Can be installed by scouts
maintains water for beavers

The team evaluated their four potential concepts against the datum of the present method (i.e. tearing down part of the dam each week). The team selected drainage ditches as the best idea. In the process of selecting their final concept, the team made their drainage ditches invisible by placing them inside plastic pipe and burring these in mud along the pound and inside old trees in the bottom of the pond.

SUCCESSES AND CHALLENGES:

Engineering students in a DFM/A course have learned to break that engineering mind set and generate divergent ideas. They have successfully adapted to a culling method to remove the "violent" ideas. They have adopted the PUGH Concept Selection Method as a filtering tool for product concepts. However, they do not want to garner together ideas to locate an appropriate broader theme for final concept generation. The reason for a Hit & Highlighting process does not seem to be important to them.

Two challenges remain in instilling the implementation of concept selection tools in the DFM/A process in today's engineering students. First, the importance of slow focused convergence on a central theme must be instilled in the students. Secondly, the ability to generate reasonable criteria, other than the direct product functions, that are parallel, distinct, equally abstract, and quantifiable.

1. C 4
2. TNT
4. Poison
5. Guns
6. Relocate River
7. Move Campground
8. Remove trees
9. Deeper River
10. Move Beavers
11. Retaining wall
12. Locks
13. Snipers
14. Natural enemies
15. Stilts for campground
16. Sterilize beavers
17 Raise campground
18 Dig Moat
19 Sump Pump
20 Aqua Duct
21 Hydro Plant
22 Drainage Ditches
23. Dam river and time water
24. Break dams
25. Build dam for them that doesn't cause floods
26. Change theme of camp
27. Teach Beavers a different 3. Acid living conditions that don't involve damning
28. Remove food
29. Pollute river
30. Electric ells
31. Let kids attack beaver dam
32. Swim in streams
33. Sounds to drive them away
34. Scents of enemies
35. Shield trees
36. Change season of camping
37. sandbags
38. cut trees for dike
39. cement wall
40. put chemicals on trees so they won't eat them
41. enslave beavers to build huts for camp
42. trapping merit badge program
43. Build a nice pond down stream for them

TABLE I An Array of Concepts Generated by A DFM/A Team

PUGH CONCEPT SELECTION MATRIX

Part 1 of 1

		CONCEPTS												
		1	2	3	4	5	6	7	8	9	10	11	12	13
		Original Concept	Cam Drive	Integrait Handle/Gear	Blade in Base									
	CONCEPT RATING		+4	0	+6									
FUNCTIONS A	Slice Carrots	D	+	+	+									
B	Shread Lettuce	A	+	+	+									
C	Grate Cheese	T	+	+	+									
D	Load (unload) Lettuce	U	+	-	+									
E	Store (release) Lettuce	M	+	-	+									
F	Facilitates Cleaning		-	-	-									
G	Facilitates Blade Selection		-	-	+									
H	Provides Eye Appeal		+	+	+									

FIGURE 1: The PUGH Concept Selection Matrix for a Manual Food Processor

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PUGH CONCEPT SELECTION MATRIX

Part 1 of 1

Lowering Water Level

			CONCEPTS												
			1	2	3	4	5	6	7	8	9	10	11	12	13
			Break Hole in Dam Daily	Sump Pump	Hydro Plant	Drainage Ditches		Plastic Drainage Pipe	with screened Riser						
		CONCEPT RATING		0	-2	+1									
FUNCTIONS	A	Costs less than $100	D	-	-	+		+							
	B	Requires little maintenance	A	+	-	S		+							
	C	Installed by scouts	T	-	-	+		+							
	D	Maintains minimum water	U	+	+	-		+							
	E		M												
	F														
	G														
	H														

FIGURE 2: A PUGH Concept Selection Matrix for Lowering Water in a Pond

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REFERENCES:

1. R.L. Firestein and D.L. Treffinger, "Ownership and Convergence: Essential Ingredients of Creative Problem Solving", *Journal of Creative Behavior,* 17(1), 1983, p.32-38
2. Isaksen, S.G., Dorval, K.B., & Treffinger, D.J., *Creative Approaches to Problem Solving,* Kendall/Hunt Publishing Co., Dubuque, IA, 1994
3. Pugh, Stuart, "Concept Selection-A Method That Works", *Proceedings, International Conference on Engineering Design,* (ICED 81), March 9 - 13, 1981
4. Tuttle, B. Lee, *DFM/A Practicum Manual,* GMI Engineering & Management Institute, Flint, MI, 1995

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