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# A METHOD FOR STRUCTURE SHARING TO ENHANCE RESOURCE EFFECTIVENESS

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## Abstract

Structure sharing is said to be observed in a product when more than one function is performed by the same structure at the same time. However, while understood at an intuitive level, and some initial measures are mooted [1], unless the concepts of structure sharing and resource effectiveness are understood at a more concrete level, their relationships are hard to establish, and harder to reinforce in a product.

Being able to develop measures of, and relationships between these two concepts should help develop products that are better structure-shared and resource-effective, hence more innovative yet competitive. This is because, structure shared products are often considered more innovative than non-structure shared products [2], and being more resource effective should amount to being simpler and less expensive. The goal of this paper is to develop a method for assessing resource effectiveness and structure sharing in a product and enhancing resource effectiveness through structure sharing.

*Keywords: structure sharing, resource effectiveness, simplicity, integration, cost*

## 1. Aims and objectives

Structure sharing [1, 2, 3] is one of the four types of sharing that can be found in a product [1]. The other types of sharing are Multi-modal integration, Structure Redundancy and Function Sharing [1]. This research aims at achieving a better understanding of the definitions of function, structure, structure-sharing (SS) and resource effectiveness (RE) in the light of physical implementation of design solutions, thereby developing a systematic approach for computing and evaluating SS and resulting RE in a given artefact. Further, guidelines are formed for improving the RE of given products through SS. This is done in terms of a method for assessing RE and SS in product and enhancing RE through SS. There are four objectives.

1. Define the concepts of function and structure more concretely than currently possible, and using them define the concepts of SS and RE so that it is possible to assess the degree to which they are fulfilled in a product.
2. Verify these definitions by matching with what designers intuitively mean by these concepts.
3. Develop a method for assessing and subsequently enhancing RE.
4. Evaluate this method for its effectiveness.

## 2. Research methodology

The following are the research questions pertaining to each objective:

1. Understanding the concepts: What is function? What is structure? What is SS? What is RE? To clarify these concepts, literature review was used to form a preliminary understanding, followed by interview of designers to understand their intuitive notions of these concepts, especially SS and RE. This was done by analysing the views of designers about the value of a set of common products given to them, which they were asked to evaluate for these values.
2. Verify these definitions by matching with what designers intuitively mean by these concepts: Review of literature was used to form initial opinions, and then adapted based on the results of interviewing designers, so that a consistent view was reflected by the definitions.
3. Develop a method for assessing and subsequently enhancing RE: How can we use the above concepts to create a measure for assessing these values? What steps are involved in this method so that more SS leads to more RE? This was based on translation of the measures into steps for product enhancement.
4. Evaluating the effectiveness of these methods: How can we tell whether the methods are effective? This was based on using the methods to improve the RE and getting these evaluated by other designers for consistent agreement.

# 3. Framework for the project

First, an understanding of functions and structures was developed. Then using this, an understanding of and measures for SS and RE were developed. This process of enquiry typically involved analysis of a product and

- Identification of the intended effects or functions.
- Identification of the processes and means to achieve these effects.
- Identification of physical entities that provide means for realizing these processes.
- As a result a function-means (FM) tree [4, 8] is formed. The links of the FM tree connect functions of the product with the physical entities that form the core of the product. FM tree helps identifying functions and structures that would be needed for evaluating SS and RE.

# 4. Developing understanding and measures:

To develop the initial understanding an interview-based survey with design students was carried out besides a study of the existing literature to check for current understanding of the concept of SS. The aims of the survey were to identify: the perceived understanding of function, structure and SS, and the degree of consistency between these observations.

## 4.1 Initial study

The participants were given a brief introduction of the concept of SS based on [1], and then four different artefacts were individually introduced to the five participants, who were then asked to exercise their judgement based on their perception of the products.

The expected results were in terms of: What are the functions of these products? What are the structures in these products? Did the subject observe SS? If yes, then where is it observed? What do the subjects observe in the function-structure relationships?

The artefacts used for the purpose of the survey are shown in Figure 1.

Figure1a. A typical chalk piece used for writing on black boards

Figure1b. Bulb packaging cover made of corrugated sheet

Figure1c. A pen cap with clip, moulded in one piece

Figure1d. A spring loaded ballpoint pen

Figure1. Artefacts used for the survey

## 4.2 Conclusions from the experiment:

- There was considerable disagreement of views among the participants as to what qualifies as a single structure. Often people identified a monolithic or single piece artefact or part as a single structure. e.g. The chalk piece.
- However, this is not universal and contradictions existed. e.g. pen cap. Some considered the single moulded pen cap as a single structure, while others believed it to have two structures, namely the cap and the projected clip arm.
- Identification of functions and the hierarchy in which they relate to the structure of the product was an issue.
    - There was general agreement that the main function relates to the intended or desired effect. This is seen as the black box representing the transformation from the input to the output, e.g., in the case of a chalk piece the main function was making a mark on the board.
    - The relative importance of functions observed in a product must be taken into account, e.g., in case of a chalk piece some of the functions were: marking on the board, provide surface to hold, transmit force, provide medium to mark, store medium and allow transfer of medium. In such a case, the relative importance of various functions is important for measuring the performance of the product in terms of SS and RE.

## 4.3. Further discussions based on the literature

Any product is an assembly of various components. It can be represented functionally or structurally depending on the way the product is looked at [5, 7]. While evaluating a product in terms of its functions, the classification can be in terms of

- Desired effect and the processes there in.
- The physical implementation for bringing in the required effect.

This classification is a complex procedure needing a structured method for identifying the various parts or components forming the overall product. One way to look into a product is to start with the basic function of the product and thereafter follow the subsequent steps to realise it. This would typically involve organs, processes and means, which would relate to physical elements, technology and principles respectively*[1][5]. FM tree is an effective and simple way of breaking down a complex system into smaller and simpler components.

SS has been identified as a desirable quality for products [1] and therefore demands greater attention and understanding. SS by definition relates directly to the functions and structures in a product. This means that the definition of function and structure and their measures have a bearing on the accuracy and reliability with which SS and RE of a product can be estimated.

A particular issue to be resolved is that functions and structures can be found at various levels of abstraction in a product [6], which brings ambiguity in choice of the functions and structures to be considered for the purpose of computing SS and RE. Such an ambiguity needs to be removed. Any methodology so developed should consider the broadest range of solutions and give an accurate and reliable measure for assessing a product for its degree of SS and RE.

## 5. Discussion on the measures developed

The phenomenon of SS is said to exist where there is more than one function being addressed by the same structure.

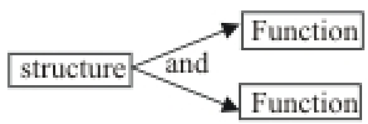


Figure 2. Structure sharing. Adapted from [1].

$$\text{Degree of SS} = \frac{\text{Number of functions at the lowest level of abstraction}}{\text{Number of structures}} \qquad (1)$$

Please note that SS was earlier mentioned in [1] as, the ratio of number of structures to the number of functions in a product. Defining SS as ratio of the number of functions to the number of structures brings consistency with understanding of SS. The higher the average number of functions per structure, the higher the SS should be.

Since, functions at the lowest level of abstraction are considered, the ambiguity in choice of functions is removed. Definitions of function and structure are given below.

**Function is defined as the intended effect, given the input conditions**. The input conditions shall include the typical environment in which the product is expected to work. In order to account for the level of abstraction we use the term main function.

**Main functions are defined as the intended effects from the system at its highest level.** In case a system has more than one main function (MF), which are independent of each other, it needs to be taken as having several MFs [6]. For example, a screwdriver is designed to fasten/ unfasten a screw, i.e., there is a distinct single desired effect from the product. However, for a screwdriver cum wrench, we have two independent functions, namely, fasten /unfasten a screw and fasten /unfasten a bolt. These functions are the desired outputs at the highest level as well as independent of each other. Each independent function will generate an independent FM tree.

**Any physical entity or feature capable of being identified independently is called a structure**. e.g., even a hole or a bend provided in a design constitutes a structure.

[1] The terms are explained in the glossary given at the end of the paper.

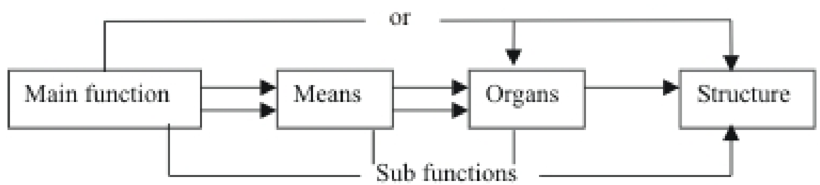


Figure 3.The process of generating a function means tree.

## 5.1 Steps for generating an FM tree:

1. Identify the MF. For the cases where there is more than one MF, each will have a separate FM tree.
2. Each FM tree starts with a MF.
3. Identify the immediate next link, which can be a supporting function, means, organ or a process. Asking the question “HOW” leads to the next level.
4. At each stage look for further branching until a structure is reached.
5. The total number of end points in an FM tree gives the total number of structures for the purpose of computing the degree of SS and RE.
6. All functions evolving in a branch for the fulfilment of some other function at an immediately higher level of abstraction are called **sub-functions.**

### 5.1.1 Example for generating an FM tree.

Let us take a screwdriver cum wrench to explain the process of generating an FM tree.

In this case, the MFs are: fastening/ unfastening of a screw, fastening /unfastening of a bolt. Since there are two MFs, two different FM trees are to be generated.

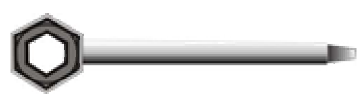

Figure 4. Schematic drawing of a screwdriver cum wrench

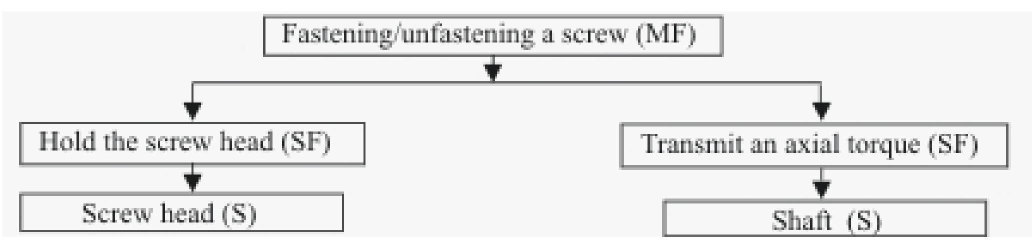


Figure 5. Function-means tree for screwdriver

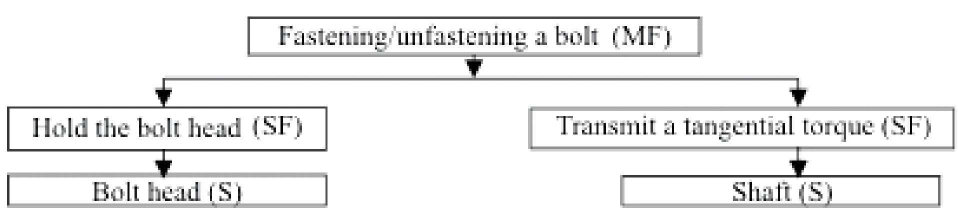


Figure 6. Function-means tree for wrench

MF = main function, SF = sub function, S = structure

In the above case there are four functions at the end of the network and altogether three structures. We can map the structure set onto the function set.

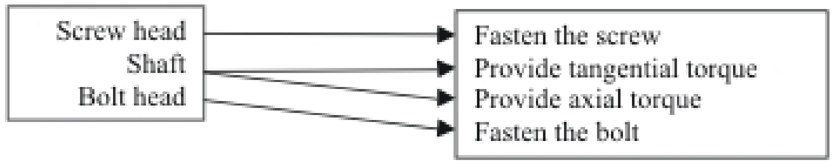


Figure 7. Mapping of structure set onto sub-function set

Using Equation 1, Degree of SS = 4/3.

### 5.2. Resource effectiveness

So far in the earlier papers the following has been said about RE:

- In general RE increases with the increase in SS [1, 2].
- RE was defined earlier as the ratio of number of structures to the number of functions these structures fulfil [1].

RE is redefined here as

$$\text{Resource effectiveness} = \frac{\text{Number of main functions}}{\text{Number of structures}} \tag{2}$$

Here philosophically, RE has been approached with the view to achieve efficiency in terms of the number of distinct physical entities used in attaining the desired functions. This may not translate into efficiency in generic terms. However, it is worth exploring the influence of RE (Equation 2) on cost effectiveness.

For the example considered above (screwdriver cum wrench) we have, RE = 2/3. According to this definition, RE is:

- Independent of the number of SFs appearing at the lowest level of abstraction.
- The measure of RE cannot be directly inferred from the degree of SS. Rather, it depends entirely on the MFs and the structures.

RE should in general be higher with mere simplification of a design. This means that for the same MF, a design with the least branching of its FM tree should have more RE. A design solution that reduces complexity in terms of the number of the SFs and structures should be more efficient.

## 6. Examples of SS and RE.

### 6.1. Example 1: Corrosion rate testing vessel

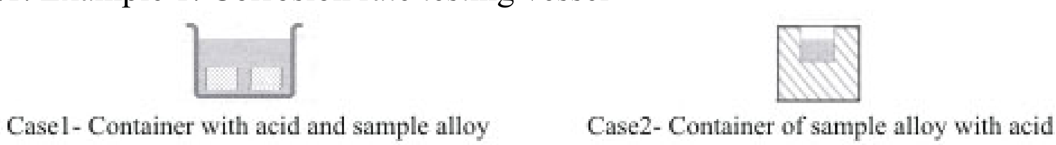


Figure 8.Corrosion rate testing vessel

There are two cases here. The first case has an acid filled container with samples of alloy dipped inside to check the rate of corrosion of the sample. The MF is to measure the rate of corrosion.

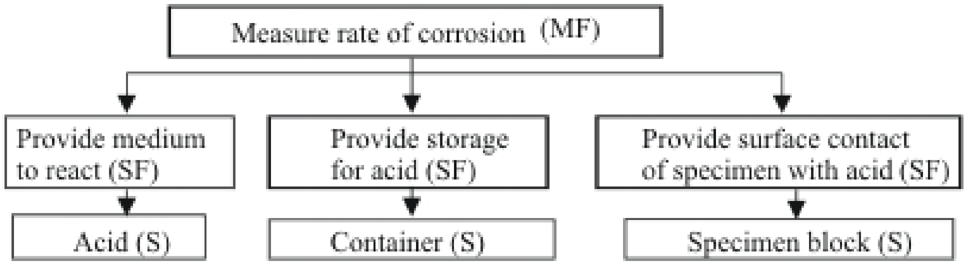


Figure 9. Function-means tree for system in case1- figure 8

Now mapping out we have,

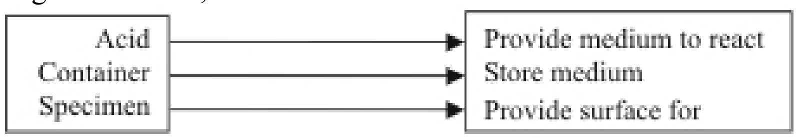


Figure 10. Structure to sub-function mapping for system in case1- figure 8

Using Equations 1 and 2, the values of the parameters in this case are:

Degree of SS = 3/3 (3 SFs, 3 S) i.e. no SS is seen here. RE = 1/3 (1 MF, 3 S).

In the second case, the container is made of sample alloy and filled with acid. Here again, the MF is to measure rate of corrosion.

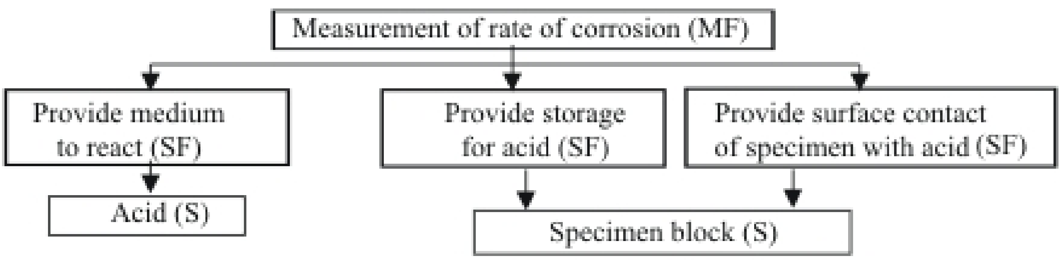


Figure 11. Function-means tree for system in case2- figure 8

Now mapping out we have,

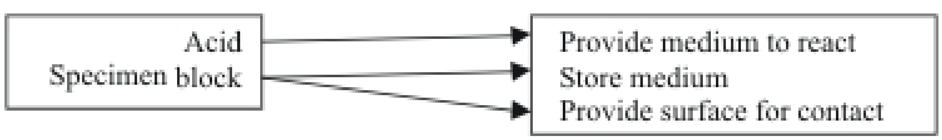


Figure 12. Structure to sub-function mapping for system in case2- figure 8

Here, the values are: Degree of SS = 3/2 (3 SFs, 2 S), RE = 1/2 (1 MF, 2 S).

## 6.2. Example 2: Writing Board

Case1- Writing board – elastic and board system    Case2- Writing board – fixed elastic and board system

Figure 13. Writing boards

First case involves a writing board with a hole and a separable elastic band. The MFs are: provide base to support, hold papers,, and hang the board.

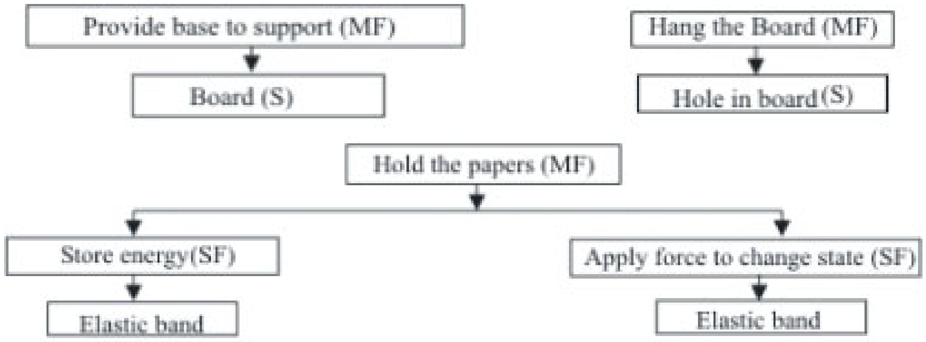


Figure14. Three Function-means trees for writing board system in case 1, figure13

Now mapping out we have,

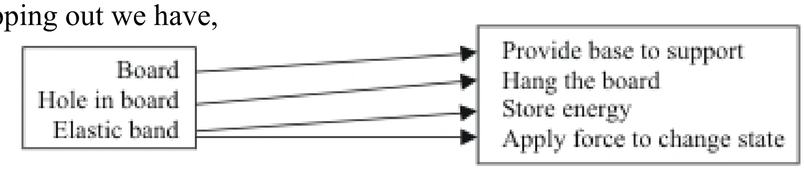


Figure 15. Structure to sub-function mapping for system in case 1, figure13

In this case the values of the parameters are: SS = 4/3, RE= 3/3.

In the other design, the board has two holes to fix the elastic band. MFs are: provide base to support, hold papers and hang the board.

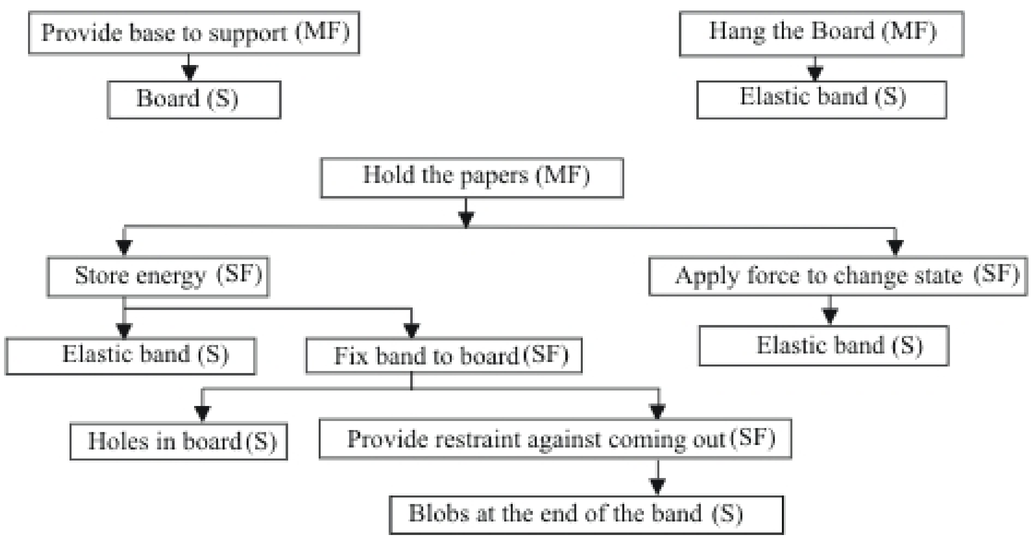


Figure16. Three Function-means trees for clipboard as shown in case2, figure13

Now mapping out we have,

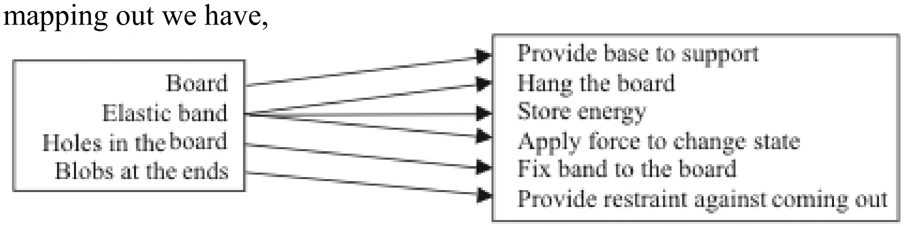


Figure 17. Structure to sub-function mapping for system in case2, figure13

In this case the values of the parameters are: SS = 6/4, RE= 3/4

In this case, the degree of SS is more even though it has less RE than in the first case. This supports our earlier inference that RE cannot always be said to be increasing with increase in SS. Keeping this in mind, guidelines for generating a more structure shared and resource effective solution have been developed.

# 7. Guidelines

The guidelines proposed here is more of a checklist of steps to ensure that the problem has been approached from different directions towards achieving the same goal of increasing RE through SS. For problems of smaller scale where the structures and corresponding functions are easier to find, one can skip the first step, though it is still recommended so as to ensure a better understanding of the problem.

1. Make a Bill of Materials (BOM) for the product and list the various functions and structures within it. The format of the BOM should be as following:

| Sl.no. | Assembly<br>├ Components<br>├ Structures | Quantity | Function(s) corresponding to each structure | Materials and Manufacturing process |
|---|---|---|---|---|

2. Identify MFs in the product and make an FM tree for each MF separately.
3. Use the BOM as a checklist to verify the completeness of the FM tree.
4. Apply one of the following to generate more structure-shared solutions.
    a. Look out for alternative solutions (principles and corresponding means, e.g., function of "apply forces" can be achieved in different ways like nuclear, gravitational, electromagnetic and so on.) to achieve the functions occurring at different levels of abstraction.
    b. Identify the properties of the structures responsible for their corresponding functions. Look for commonalities of properties in different structures within the same FM tree. Try eliminating one of the structures by using the property common with the other structure for fulfilling the function(s) performed by the former. This is applicable to overlapping properties across the different FM trees within the product.
    c. Apply the earlier steps in various branches within the tree. For this purpose one can move either bottom up or top down.
    d. Reduce the number of repeating elements for the same function (multiple elements resulting in Function Sharing).
    e. Within a given part try integration through creative designs and selection of appropriate manufacturing processes.
    f. Try reducing the number of assemblies by appropriate integration at the point of assembly.
    g. Reduce the need for separate fasteners by appropriate connectors like snaps and fits.
    h. Try reducing the variety in the use of different manufacturing processes within a product.

# 8. Experimental Evaluation

In order to evaluate the guidelines, experiments were conducted in three phases:

- Phase 1- with researchers: to check the usability of the guidelines.
- Phase 2- with groups of non-experienced designers: to compare the method effect with group effect.
- Phase 3- with experienced designers: to check whether the guidelines can help generate more and better concepts (in expected terms) than otherwise.

Once the guidelines were found usable by trying them on given problems by the researchers involved, these were ready to be taken to the next phase.

## 8.1 Experiments in Phase 2

In the second phase two teams of two members each were used. Two design problems were selected and each team was asked to solve each of these problems, one without any guidelines and the other with the help of these guidelines. In order to reduce the influence on the result due to the inherent difference in creative ability of the teams, the problems were swapped as shown in the table1.

| | Group 1 | Group 2 |
|---|---|---|
| Problem 1 | With guidelines | Without guidelines |
| Problem 2 | Without guidelines | With guidelines |

Table1: matrix showing the problems and the groups involved

Problem1 involved the Redesign of a given camera tripod stand. Problem2 was about redesigning a given clipboard. The first session involved problem solving without guidelines, while the second session involved problem solving with guidelines.

### 8.1.1 Findings from the experiments in Phase 2

Findings from the experiments in phase 2 are given below.

- There was not much difference in the number of concepts generated with or without guidelines.
- Quite a few concepts generated without guidelines were not as resource effective as the given solution.
- The concepts generated with the help of guidelines were focused and similar in nature. The concepts generated here were more resource effective than the given solution. Many a times the concepts generated later were an improved version of the ones generated earlier.
- In most cases a better structure-shared solution was also more resource effective. Besides, in general, a more resource effective solution was also cost effective unless the newer solutions were altogether different at concept, materials or process level.
- Table 2 and Table3 summarise the outputs of this experiment.

### 8.1.2 Experiment1- Redesign of given tripod stand.

A regular stainless steel camera tripod stand was given. The values of the parameters for the given tripod stand are: SS = 71/53, RE = 3/53, Approx. Cost (C) = Rs. 780-/-

| No. | Group1 (without method) | | | | | Group2 (with method) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Solution | Features | SS | RE | C | Solution | Features | SS | RE | C |
| 1 | Ball and socket | | - | - | - | Ball and socket | | - | - | - |
| 2 | Material reduction | More structures | 71/ 55 | 3/ 55 | 760 | Modified legs | Fewer structures | 71 / 50 | 3/ 50 | 760 |
| 3 | Remove a tier of extension | Function quality reduced. | - | - | - | Remove a tier of extension | Function quality reduced. | - | - | - |
| 4 | Flexible tube | Novel concept, fewer structures | - | - | - | Pedestal type | Simpler, function quality reduced | 57/ 36 | 3/ 36 | 725 |
| 5 | | | | | | Modified locking | Use of fits | - | - | - |

Table2: Solutions generated for the Tripod stand in phase 2

The vacant cells marked with a dash mean that the concepts were not detailed enough to calculate the number of structures correctly. The costs shown here are approximately the direct variable cost [8, 9], and include material costs, processing costs, labour costs and the assembly costs.

### 8.1.3 Experiment2- Redesign of given writing board

A regular hard board-writing pad with a sheet metal clip was given. The values for the given writing board are: SS = 7/13, RE = 3/13, Approx. Cost = Rs. 8.50-/-

| No. | Group2 (without method) | | | | | Group1 (with method) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Solution | Features | SS | RE | C | Solution | Features | SS | RE | C |
| 1 | Profile change | More complex | 8/ 15 | 3/ 15 | 8.5 | Base-pad integrated | fewer structures | 6/1 0 | 3/ 10 | 6.0 |
| 2 | Cut & bend | Fewer structures | 5/5 | 3/5 | 5.5 | Moulded parts | Fewer structures | 6/5 | 3/5 | 5.0 |
| 3 | Different clamping system | Same complexit y | 9/ 15 | 3/ 15 | 6.5 | Different clamping system | Fewer structures | 6/8 | 3/8 | 6.5 |
| 4 | Plate Clamp | Fewer structures | 7/5 | 3/5 | 5.0 | Holder type | Integratio n, simpler | 4/4 | 3/4 | 4.5 |
| 5 | Push ball | Fewer structures | 7/6 | 3/6 | 5.0 | Plate clamp | Fewer structures | 6/6 | 3/6 | 5.0 |
| 6 | | | | | | Bar clip | Fewer structures | 9/7 | 3/7 | 6.0 |
| 7 | | | | | | Pad elastic band | Simpler, fewer structures | 4/3 | 3/3 | 4.0 |
| 8 | | | | | | Corner pockets | repeating structures | 4/3 | 3/3 | 4.0 |

Table3: Solutions generated for the writing board in phase 2

## 8.2 Experiments in Phase 3

In third phase experienced designers were used. The individual designers were given the same problem in both the sessions. Guidelines were introduced to them only in the second session. This was done to see whether the guidelines could help them generate further concepts on the same problem on which they have already worked. Further it would also facilitate the comparison of the solutions generated in the two sessions.

The observations from these experiments were similar to those in the second phase. The results of the experiments have been listed below in the tables 4 and 5.

### 8.2.1 Experiment- Redesign of given spotlight

An Aluminium lampshade with a mounting system was given. The values for the given writing board are: SS = 28/26, RE= 4/26, Approx. Cost (C)= Rs. 125-/-

| No. | Participant 1 | | | | | Participant 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Solution | Features | SS | RE | C | Solution | Features | SS | RE | C |
| 1 | Spherical shade | Function quality reduced | - | - | - | Vacuum clamping | Reduced complexity | 27/ 21 | 4/ 21 | 105 |
| 2 | Coiled wire shade | Fewer structures | 22/ 16 | 4/ 16 | 80 | Integrate bulb and shade | Complex | - | - | - |
| 3 | Modified clamp | Function quality reduced | - | - | - | Thick insulated wire | Fewer structures | 20/ 17 | 4/ 17 | 95 |
| 4 | Eye ball shade | Function quality reduced | - | - | - | Eye ball shade | Function quality reduced | - | - | - |
| 5 | Flexi-Shade | Fewer structures | 24/ 19 | 4/ 19 | 95 | Flexi-holder | Fewer structures | 28/ 26 | 4/ 26 | 115 |
| 6 | | | | | | Reflecting mirror | More structures | 20/ 18 | 4/ 18 | 80 |

Table4: Solutions generated for the Spot light in phase 3 without method

| No. | Participant 1 | | | | | Participant 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Solution | Features | SS | RE | C | Solution | Features | SS | RE | C |
| 1 | Ball joint -changed base | Fewer structures | - | - | - | Holder and shade integrated | Fewer structures | 24/ 22 | 4/ 22 | 90 |
| 2 | Thick wire | Fewer structures, simple | 20/ 17 | 4/ 17 | 95 | Holder-bulb integrated | Complex | - | - | - |
| 3 | Moulded shade | Fewer structures, | - | - | - | Modified bulb | Integration | - | - | - |
| 4 | Flexi-tube, coating | Physical shade removed | 16/ 16 | 4/ 16 | 40 | | | | | |

Table5: Solutions generated for the Spot light in phase 3

Some of the feedbacks received from the participating designers were:

- Though the BOM and FM tree help in understanding the given design better, they consumed a significant proportion of time allocated for the experiments.
- It was generally felt that generating the FM tree needs some practice.
- An earlier exposure to methods like Design For Manufacture and Assembly (DFMA) was helpful in understanding the guidelines.

# 9. Comparison with related methods

A discussion on these guidelines would remain incomplete without an appropriate comparison with the related methods namely Value Analysis (VA), DFMA, Function Analysis System Technique (FAST) and Subtract and Operate (SOP) [8, 9, 10].

VA is based on the application of function analysis to the component parts of a product. It supports cost reduction activities by relating the cost of components to their function contributions.

FAST builds upon VA by linking the simply expressed, verb-noun functions to describe complex systems. FAST differs from VA in the use of intuitive logic to determine and test function dependencies and the graphical display of the system in a function dependency model. Another major difference is in analysing a system as a complete unit, rather than analysing the components of a system. Unlike the FM tree, FAST does not give structures at the end of the tree. It only shows the MF and SFs.

On the other hand, SOP focuses on component elimination. This not only narrows down concept exploration but also inherently misses the function details that would otherwise be understood at a structure level.

VA or Function Analysis provide methods for identifying the problem and defining the functions that need to be performed. It does not suggest guidelines or methods to generate solutions. Performing VA or producing the FAST model and analysing functions with the VA matrix are only the first steps in the process. Further work must involve developing and analysing potential improvements in the product.

The guidelines therefore should work well in conjunction with the VA process and build on from where function analysis ends.

DFMA guidelines look similar at first glance. However, the difference lies in the fact that we are primarily interested in looking at structure level rather than component level. The DFMA guidelines also talk about integration and part reduction but do not suggest methods and approaches to do the same. DFMA guidelines should work well with the guidelines proposed above to make design solutions more resource effective.

Once the concepts have been generated, the measure of RE should help concept evaluation better and in a more objective way.

# 10. Conclusions and future work

Functions and structures in a product can be identified using an FM tree. The FM tree for a product also helps in evaluating its degree of SS and RE. The functions and structures occur at various levels of abstraction in an FM tree. While for evaluation of SS, the structures at the lowest level of abstraction are used; RE is calculated using the total number of functions at the highest level of abstraction. It is important to note that in cases where the MF also relates immediately to a structure, then for the purpose of calculation of SS, it is also considered as an SF, i.e., functions considered for the purpose of evaluating SS are those that immediately precede a structure.

SS is the ratio of number of functions at the lowest level of abstraction to the number of structures in a product. RE is the ratio of number of functions at the highest level of abstraction to the total number of structures. This implies that the measure of RE cannot be directly inferred from the degree of SS. Rather, it depends on MFs and structures. However, RE of a product can usually be increased through improved SS, which has also been found to increase the cost effectiveness of the product in general.

Following are some of the limitations of the current status of the guidelines, which are likely to modify the values of SS as well as RE:

- Accounting for the quality of function (QOF): QOF refers to the nature of function, the extent to which a structure fulfils a function and how efficiently the function is fulfilled. The QOF has not been considered so far. However there seems to be a clear indication that the QOF has a definite role to play while considering RE. This area needs to be explored.
- Accounting for the harmful functions in the design: So far only the positive functions are considered i.e. Harmful functions do not feature in the discussions and they are not accounted for.
- Currently there is no provision for penalizing the design solutions that generate additional SFs. This needs to be explored and incorporated.
- RE has so far been discussed with respect to the function module only. However, it has also to be looked from production and retirement phases of the life cycle so as to obtain a more integrated assessment.

## 11. Glossary

An organ is a material-element or an interaction between several material-elements based on a physical regularity, which create the desired effect. Organs may include a set of structures participating together in bringing an effect.

Means are the principles, laws or phenomena that are responsible for the occurrence of the function.

Any step in the transformation of the various operands viz. materials, energy or information, which alters one or more properties of the operand in an appropriate direction is a Process or Operation.

Technology is the interaction between the operands and the necessary effects (force, the effects of heat, movements, flow changes and so on), which affect the operand [5].

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