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A SOLUTION ORIENTED APPROACH TO REQUIREMENT IDENTIFICATION

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Abstract

Descriptive studies often show that designers generate solutions even during problem understanding, a trend classically discouraged by design methodology. In problem understanding solutions are generated but not elaborated, whereas in problem solving they are generated and elaborated. Developing solution neutral requirements should be our ideal goal, as this least constrains the solution space, which helps develop solutions of greater novelty and quality.

However, predicting appropriate requirements is difficult, as indicated by the failure of a large number of products in the market. Research shows that in focus group meetings, potential users can give better feedback about their wishes if solutions are already shown to them. We feel that solutions available should be used as an aid, rather than hindrance, to identify and clarify requirements. Here, we propose a method for requirement identification and understanding in which potential and existing solutions, if any, to fulfil the requirements initially identified are analysed to clarify the preferences of all stakeholders as to what the requirements of a product should be. This paper outlines this method and its evaluation using comparative empirical studies. These studies show that the method is effective and efficient in accurately identifying a large number of requirements reflecting a design problem.

1. Aims and objectives

Descriptive studies often show that designers generate solutions even during problem understanding [1, 2, 3], a trend classically discouraged by design methodology. It is also observed that problems and solutions co-evolve [1, 2], and explained as to why they must do so [3] and why it is impossible to use solution neutral problem statements to guarantee generation of any solutions to fulfil these requirements [4]. This inevitably coupled nature of goals and means is utlised by Hubka in his function-means tree in developing a design by intertwining functions and means - functions leading to means leading to functions. Nidamarthi et al. [2] distinguish problem understanding from problem solving by how solution proposals generated are used: in problem understanding they are generated but not elaborated, and used only as an aid in understanding the problem, whereas in problem solving they are generated as well as elaborated. Developing solution neutral requirements should be our ideal goal, as this least constrains the solution space, and allows development of the widest possible range of solutions with potential for greater novelty and quality. Various aids are also available to help develop a requirements list; two notable ones are QFD house of quality [5] and requirement checklists [6].

While checklists help look at a problem afresh and identify potential requirements to solve the problem, QFD helps start from customer requirements and transform them into engineering targets. In both these, however, the potential requirements, whether coming from the product development team, the customer, user or all stakeholders, predicting appropriate requirements is a difficult task. The failure of a large number of products in the market may be a partial indication of this; more indications come from studies that show cases where over 40% of failure in the products are due to insufficient identification or satisfaction of requirements [7]. A telltale sign often seen in student evaluation of concepts generated is that the gut feelings about the worth of the solutions often do not match the evaluation produced using the metrics and requirements identified a priori. Research also shows that in focus group meetings, potential users can give a better feedback about what they want if solutions are already available to them.

We, therefore, feel that solutions available should be used as an aid, rather than hindrance, to identify and clarify requirements, and propose a method for requirement identification and understanding in which potential as well as existing solutions, if any, to fulfil the requirements initially identified are analysed to identify the preferences of all the stakeholders as to what the requirements of a product should be. The objective of this paper is to outline such a method and evaluate its efficacy vis-à-vis available methods.

2. Research methodology

There are two major steps in the methodology:

- Carry out literature survey to identify the efficacy of existing methods and identify the requirements for the proposed method, and develop the proposed method, so that it can be used independently or in conjunction with the existing methods
- Evaluate the efficacy of the method against that of the main existing methods.

3. Proposed Method

Study of literature shows that existing requirements identification and clarification aids have a major problem identifying reliable requirements that reflect the voice of the stakeholder. Even though a stakeholder may be reasonably confident about the reliability of a requirement, there is no objective way of justifying this, and often, retrospective analysis of requirements identified earlier are changed or modified after solution generation. Also, current techniques do not allow systematic identification of requirements based on the properties of the existing solutions, but rather only allow their benchmarking against requirements already identified.

The method developed has the following, broad steps:

- Identify the major problem areas addressed by the intended product, and identify whatever requirements are possible to identify, with(-out) using existing methods

- Using this as the initial list of requirements, generate a list of ideas for solutions; bring them to a state where they can be inspected and commented upon by others
- Use focus group of stakeholders to identify good and bad properties of these solutions
- Use these properties to modify the list of requirements, so that these are reflected in the list of requirements;
- Use this modified list, in conjunction with other methods or otherwise, to finalize the list of requirements.

4. Evaluation Methodology

In order to evaluate the method we constructed the following set of design experiments, see Table 1. In each experiment a design group was handed in a deign problem and a specific intervention to be used in the design process, and was asked to identify a list of requirements, classify them into demands and wishes, and indicate a measure for the requirement where possible. There was no time constraint imposed.

Table1: Matrix showing the problems and the groups involved

Group 1	Group 2	Group 3
Without methods,P1	Without methods,P2	Without methods,P3
With lifecycle checklist,P2	With lifecycle checklist,P3	With lifecycle checklist,P1
With proposed method, P3	With proposed method, P1	With proposed method, P2
With lifecycle checklist & concepts from last expt, P3	With lifecycle checklist & concepts from last expt, P1	With lifecycle checklist & concepts from last expt, P2

Three groups of designers, each containing two designers, were used. Two design groups contained an experienced designer and a novice designer, while the other contained two novice designers. The goal was to see whether the method enhanced requirement identification performance irrespective of designer experience.

Three design problems were used, see Appendix 1. The problems were used in a cyclic order so that each problem was used in each type of design experiments (i.e., involving a each type of intervention).

Four types of intervention were used, see Appendix 2. In the first type, design groups were asked not to consciously follow any particular method. This was used as a datum for comparison of the effect of other intervention, and was the first set of experiments to be conducted. In the second set of experiments, each group was asked to identify requirements for the problem specified using a life cycle checklist [8]. The reason was to emulate the scenario of having a focus group of stakeholders from all phases of the product life cycle, who were to work together generating requirements for the product without any product idea available. The results of the experiments would also suggest the efficacy of using this checklist for identifying requirements. The third set of experiments involved using the proposed method (and no other method) in the requirement identification process. The goal was to see how use of the method fared using designers only, as opposed to (emulated) use of a focus group of stakeholders representing the product life cycle. Finally, the fourth set of experiments involved using the concepts generated in the third set of experiments, and scrutinising them to identify requirements using the life cycle checklists. This gave an emulation of the use the proposed method by a focus group of stakeholders, and therefore emulated use of the proposed method exactly as suggested. Actual use of a group of stakeholders, even though preferable, was logistically difficult to obtain for these experiments.

The total number of requirements generated in each experiment was noted down. The quality of the requirements generated were evaluated by a larger group that included all the designers who took part in the experiments. For each requirement they asked the following questions:

- Should this requirement be considered at all as a requirement for this problem?
- If yes, should this be considered a demand or a wish?

Along with these, the amount of time taken by each design team for each experiment was also noted. The number of concepts generated and explored in the last two types of experiment were also noted down. Using the answers of evaluation questions asked by the designers, following criteria were used for comparative evaluation:

- How do the total numbers of requirements identified right (i.e., what is identified should be a requirement, be it a demand or a wish) compare between the various types of experiment? It is assumed that the more the number of right requirements identified, the better it is.
- How do the percentages of requirements identified right compare between the various types of experiment? It is assumed that the more the percentage of right requirements identified, the better it is.
- How do the total numbers of requirements identified in the right category (i.e., whether a requirement is categorised as a demand or wish as it should be) compare between the various types of experiment? It is assumed that the more the number of requirements in the right category, the better it is.
- How do the percentages of requirements identified in the right category compare between the various types of experiment? It is assumed that the more the percentage of requirements identified in the right category, the better it is.

In addition, links between amount of time spent and number of requirements identified, and number of concepts identified and explored and their links with the number of requirements identified were also investigated.

5. Evaluation Results

Results of evaluation are presented in four sub-sections. Section 5.1 discusses overall comparison of methods for their efficacy (number and quality) of requirement identification. Section 5.2 compares overall time-efficiency of the different methods for requirement identification. Section 5.3 discusses the relationships between the number of concepts generated and explored and their influence on the number of requirements identified.

5.1 Effectiveness of Requirement Identification

Table 2 shows results of evaluation as an aggregate (for all the groups) for each type of experiment.

The following are the broad conclusions from the results in Table 2. First of all, the number of right requirements identified is small whenever life cycle checklist is not used, and large with checklist, see Column 2 of Table 2. In other words, use of stakeholders from all phases of the life cycle has a major impact on the number of requirements identified.

Table2: Aggregate Evaluation for Each Intervention

Aggregate for all groups	No. right req.	No. wrong req.	No. D/W right	No. D/W wrong	%right-on-total	%right-D/W-on-total-right	%right-D/W-on-total
Without method	40	1	30	10	98%	75%	74%
Checklist	104	8	85	20	93%	81%	75%
Proposed method w/o checklist	57	0	46	11	100%	81%	81%
Proposed method with checklist	93	1	76	17	99%	82%	81%

The second conclusion is (see Column 3, Table 2), use of checklist alone can also lead to identification of a large number of wrong requirements, while this number is very small in cases in which the proposed method is used. This is further clarified by the percentage of right requirements identified (Column 6) which is highest when the proposed method is used, with or without checklist, and least when checklist is used without the proposed method.

The third conclusion is (see Column 4), the number of requirements categorised into the right category has a similar trend to that of the number of right requirements identified: use of stakeholders from all phases of life cycle or a life cycle checklist has a major impact on the number of requirements identified into the right category.

The fourth conclusion is, that use of methods has some impact on the percentage of right requirements identified (Column 7). Note that is higher than all the other case, albeit by a small margin, when the proposed method is used, with the checklist, and least when no method is used.

The fifth conclusion is (last column in Table 3, the figures denote the product of the two percentages given in Columns 6-7), combined accuracy of determining right requirements and categorising requirements right is substantially higher in cases in which the proposed method is used, with or without the checklists.

On the whole, the trend seems to be that the proposed method in general has a strong positive impact on quality (i.e., accuracy) of requirements identified, and in its complete form (i.e., when used all stakeholders wishes, as emulated using checklists) produced a large number of requirements.

5.2 Efficiency of Requirement Identification

Table 3 lists the amount of time spent by each group in the various experiments and the number of requirements generated by the in these experiments.

Since for each type of experiment the specific problem used by a group is different, the average numbers are probably a better indication of the performance by each intervention rather than performance by individual groups. By comparing the average values for each type of experiment, we see that the t/r ratio (i.e., average time to generate one requirement) is the least in the case of using checklists only and most in the case without methods, with use of methods in between. Since the values of this ratio for the types involving the proposed method are around the average value of this ratio for all experiments put together, using the proposed method appears to have an average efficiency of requirement identification, and is not as efficient as checklist method, although more efficient than in the cases of using no method.

Table3: Time Spent and Number of Right Requirements per Group

	W/o method			Checklist			Proposed method			Proposed method+checklist			all
	Time (t)	No-req (r)	t/r	Time (t)	No. req (r)	t/r	Time (t)	No. req (r)	t/r	Time (t)	No. req (r)	t/r	t/r
G1	69	9	7.7	89	34	2.6	47	14	3.4	97	21	4.6	4.6
G2	110	22	5	125	33	3.8	103	16	6.4	158	29	5.4	5.2
G3	96	9	10.7	79	37	2.1	130	27	4.8	178	43	4.1	5.4
Av.	91.7	13.3	6.9	97.7	34.7	2.8	93.3	19	4.9	144.3	31	4.7	4.8

Table 4 gives results similar to Table 3, except for number of requirements rightly categorised. Again, the average numbers are a better indication of the performance by each intervention rather than performance by individual groups. By comparing the average values for each type of experiment, we see that the t/r ratio (i.e., average time to generate one requirement) is the least in the case of using checklists only and most in the case without methods, with use of proposed method in between. Since the values of this ratio for the types involving the proposed method are around the average value of this ratio for all experiments put together, using the proposed method has an average or above efficiency of requirement identification, and is not as efficient as checklist method, although more efficient than using no method.

Table4: Time Spent and Number of Requirements Rightly Categorised per Group

	W/o method			Checklist			Proposed method			Proposed method+checklist			all
	Time (t)	No-req (r)	t/r	Time (t)	No. req (r)	t/r	Time (t)	No. req (r)	t/r	Time (t)	No. req (r)	t/r	t/r
G1	69	6	11.5	89	27	3.3	47	11	4.3	97	18	5.4	6.1
G2	110	15	7.3	125	27	4.6	103	14	7.4	158	24	6.6	6.5
G3	96	9	10.7	79	31	2.5	130	21	6.2	178	34	5.2	7.5
Av.	91.7	10	9.2	97.7	28.3	3.5	93.3	15.3	6.1	144.3	25.3	5.7	6.1

5.3 Relationships between Concept Generation and Requirement

Identification

The following Table is used to analyse the relationships between concept generation and requirement identification (in the proposed method).

Table5: Concept Genratation and Requirement Identification

	No. of concepts generated	No. of concepts explored	No. original req	No. of addl req	No. addl. Requirements / Total no. requirements	No.addl req per concept explored	Ratio per concept explored
G1-proposed method	12	12	14	0	0	0	0
G2-proposed method	7	7	8	8	0.5	1.14	0.07
G3-proposed method	2	2	14	11	0.44	5.5	0.22
Av.	7	7	12	6.33	0.35	0.9	0.05
G1-method+ checklist	12	3	12	9	0.43	3	0.14
G2-method+ checklist	7	7	18	11	0.38	1.57	0.05
G3-method+ checklist	2	2	29	14	0.33	7	0.17
Av.	7	4	19.67	11.33	0.37	2.83	0.09
Av. (all)	7	5.5	15.88	8.83	0.36	1.87	0.07

Rows 2-4 describe statistics for various groups using the proposed method without checklist. Row 5 describe the average of these. Rows 6-8 describe these for various groups using the proposed method with the checklists. Row 9 describes the average of these. Row 10 describes average of the averages. On an average 7 concepts were generated per experiment, and 5.5 concepts were explored in identifying additional requirements.

Columns 2-3 show respectively the number of concepts generated and explored in various experiments. Columns 4-6 describe, respectively, the number of requirements generated originally in the experiments, the number of additional requirements generated in response to analysing the concepts generated, and the ratio of the two. In the experiments that used proposed method without checklists, the average number of requirements originally generated were 12 in contrast to 19.67 when the method is used along with checklist; the figures are 6.33 and 11.33 respectively for the number of additional requirements identified analysing concepts developed. As can be seen from Column 6, an average of 35-37% additional requirements are generated by analysing concepts – a substantial contribution of the method. Another way of looking at it is as in Column 8, which shows the ratio of additional requirements generated per requirement per concept explored. For each concept explored 7% of all requirements generated (with or without using concepts) are generated. Given that one can increase the number of concepts to be explored, the total number of additional concepts should also increase accordingly.

Column 7 shows that an average of 1.87 requirements are generated per concept explored (although the actual number varies between 0 and 7 requirements per concept). This indicates the potential of using concepts for requirement identification.

6. Summary, Conclusions and Future Work

To summarise, a method has been developed for using concept generation as an aid to requirement identification, and has been evaluated for its effectiveness and efficiency in requirement identification.

Evaluation involved comparison of the performance of the proposed method with using no method, using life cycle checklists (which emulated requirement identification by a stakeholder group without using concepts to aid the process), using the proposed method by designers only (emulating the case where only designers, and no other stakeholders would be involved), and one in which proposed method is used with checklists (emulating use of concepts by stakeholders to identify requirements). It has been found that the proposed method, when used with checklists was almost as effective in identifying a large number of right requirements (as did checklists without the proposed method), and do so more accurately than checklists. It was more effective than the other two cases (without method, and with proposed method but not checklists).

The efficiency of the proposed method when used with checklists was above average and better than all methods except the checklist method used alone.

It is also noted that exploration of each additional concept led to identification of up to 7 additional requirements, which indicates the potential of such a method when applied on a large set of concepts.

In summary, we claim that solution generation should be a reliable means by which solution neutral requirements can be generated, and it should be included as an aid to requirement identification. We also believe that this would lead to more reliable measures to qualify or quantify a requirement, since these measures would be based on properties of realistic concepts, particularly those of existing concepts, if any. However, this is yet to be tested. Further work involves exploring further variants of the method, and evaluating them using a larger set of criteria and designers.

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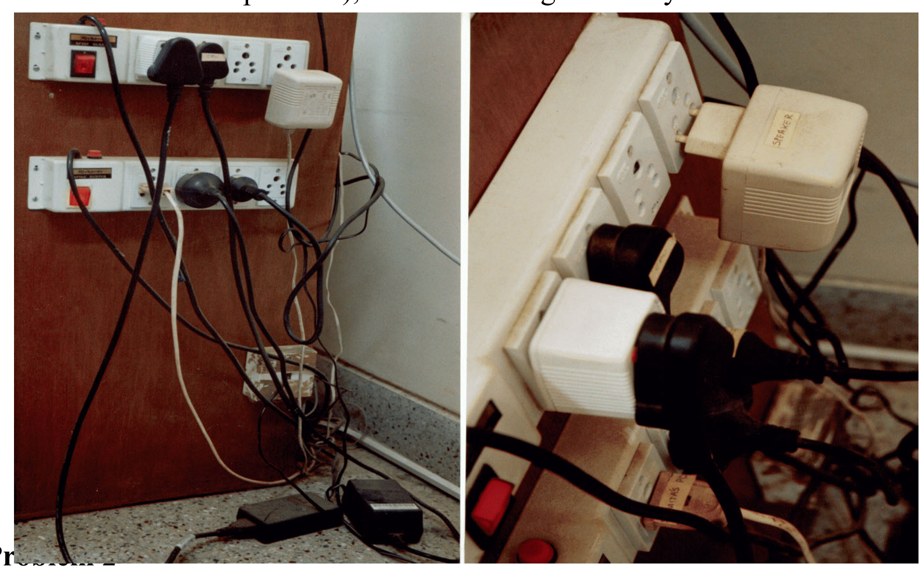
7. Appendix 1

Following are the three problems used in the design experiments.

Problem 1

Use of computers has increased drastically in the recent past. Though computer is a boon for people belonging to all spheres of the society, it has also created certain problems. With the use of increased numbers of computer, specifically in a small room, the use of several numbers of connectors, sockets, extension cords etc. has also increased. Apart from computers, users also use peripherals of computers, such as printers and scanners, the use of which has exaggerated the problem. Several wires of different shapes, sizes and capacity are just jumbled together. Some of the related problems are electrical hazards, difficulty of moving through the wires and that of identifying problems. There are also problems with the connector endings, as they come in several styles and numbers, and connecting them to a UPS is often a problem.

Develop a list of requirements to solve this problem. Please list down the requirements of the problem in a sheet of paper (specifying the demands and wishes and their measures if possible), after discussing these in your team.



Problem 2

Present day's executives are accustomed to using a gamut of modern gadgets. Some examples of gadgets are: Pen, pencil, eraser, mobile, spectacle, keys, purse, credit cards, handkerchiefs, mobile charger, digital diary etc.

But often the space available in their attire does not permit them to carry all these gadgets comfortably. Develop a list of requirements to solve this problem. Please list down the requirements of the problem in a sheet of paper (specifying the demands and wishes and their measures if possible), after discussing these in your team.

Problem 3

We use different brooms to clean different areas in our house. To clean dry surfaces one type of broom is used; to clean wet surfaces another type of broom is used. We use cloth or sponge to remove water. To remove spider-nets we use other types of broom. There is lot of manual effort involved in cleaning. A common problem in using many of these pieces of equipment is that they make air dusty in the areas where cleaning is done, which requires additional time to clean. Also, there is difficulty involved in cleaning corners using these equipments.

The task is to design a product that will help in solving these problems. Users should be able to clean interior and exterior areas of a house, including windows, doors, floors and roofs. The product should remove dust, water and dirt accumulated in the corners as well. The product should require only one person to operate. Develop a list of requirements to solve these problems. Please list down the requirements of the problem in a sheet of paper (specifying the demands and wishes and their measures if possible), after discussing these in your team.

The goal of each exercise in this set of design experiments is for the team to analyse the design problem given, and develop a list of requirements, suitably divided into demands and wishes, with their respective measures if possible. The instructions given must be strictly adhered to, especially with respect to non-use or exclusive use of specific methods.

- Design Problem: A situation with which someone is discontent, and a more desirable situation can be conceived which is realisable
- Requirements: Objectives that should be satisfied by the product to be designed
- Demands: Requirements that MUST necessarily be satisfied by the product, without satisfying these, the product will not be acceptable as a solution to the design problem
- Wishes: Requirements that would be desirable to be satisfied by the product; these would make an acceptable solution more desirable
- Measure/metric: A measure or a metric for a requirement is a qualification or quantification of its requirements.

8. Appendix 2

Following are the instructions used for intervention in the four types of design experiments.

Method 1 (no method)

Do not consciously use any method for developing the list of requirements for this exercise.

Method 1 (Checklist)

List Objectives

- Identify the processes in which the product should function, and identify the persons involved (stakeholders)

- Make an inventory of the wishes, preferences, needs, and the like of the persons involved. Utilize checklist provided

Checklist

- *Performance*
Which function(s) does the product has to fulfil? What are the parameters by which the functional characteristics will be assessed (speed, power, strength, accuracy, capacity, etc.)?
- *Environment*
To which environmental influences is the product subjected during manufacturing, storing, transportation and use (temperature, vibrations, humidity, etc.)? Which effects of the product on the environment should be avoided?
- *Life in service*
How intensively will the product be used, how long does it have to last?
- *Maintenance*
Is maintenance necessary and available? Which parts have to be accessible?
- *Target product cost*
How much may the product cost, considering the prices of similar products?
- *Transportation*
What are the requirements of transport during production, and to the location of use?
- *Packaging*
Is packaging required? Against which influences should the packaging protect the product?
- *Quantity*
What is the size of run? Is it batch or continuous production?
- *Manufacturing facilities*
Should the product be designed for existing facilities; are investments in new production facilities possible? Is (a part of) the production going to be contracted out?
- *Size and weight*
Do production, transport, or use put limits as to maximum dimensions or weight?
- *Aesthetics, appearance and finish*
What are the preferences of the consumers, customers? Should the product fit in with a product line or house style?
- *Materials*
Are special materials necessary? Are certain materials not to be used (for example in connection with safety or environmental effects)?
- *Product life span*
How long is the product expected to be produced and marketable?
- *Standards*
Which standards (national and international) apply to the product and its production? Should standardization within the company or industrial branch be taken into account?
- *Ergonomics*
Which requirements, with regard to perceiving, understanding, using, handling, etc., does the product have to meet?
- *Quality and reliability*
How large may 'mean times before failure' and 'mean times to repair' be? Which failure modes, and resulting effects on functioning, should certainly not occur?
- *Shelf life and storage*
Are there during production, distribution, and use (long) periods of time in which the product is stored? Does this require specific 'conservative' measures?
- *Testing*
To which functional and quality tests is the product submitted, within and outside the company?
- *Safety*
Should any special facilities be provided for the safety of the users and non-users?
- *Product policy*
Does the current and future product range impose requirements on the product?
- *Social and political implications*
What is the public opinion with regard to the product?
- *Product liability*
For which unintended consequences of production, operation and use can the manufacturer be held responsible?
- *Installation, operation*
Which requirements are set by final assembly and installation outside the factory, and by learning to use and operate the product?
- *Re-use, recycling, disposal*
Is it possible to prolong the material cycle by re-use of materials and parts? Can the materials and parts be separated for waste disposal?

Method 3 (Proposed Method without Checklist)

1. Identify the major problem areas addressed by the intended product, and identify whatever requirements are possible to identify without a method
2. Using this as the initial list of requirements, generate a list of ideas for solutions; bring them to a state where they can be inspected and evaluated by the team

3. Empathising as potential stakeholders, identify good and bad properties of these solutions
4. Use these properties to modify the list of requirements, so that these are reflected in the list of requirements
5. Go to Step 2 if necessary, and loop down to Step 5, as many times as you think is necessary
6. Use this modified list to finalize the list of requirements.

Method 4

- Take the results from your previous exercise (the list of solution ideas and the list of requirements) as the initial basis for this exercise.
- Question each idea for its good and bad properties by using the questions in the checklist provided
- Use these additional properties to modify the list of requirements, so that these are reflected in the list of requirements
- Use this modified list, to finalize the list of requirements.

Use the checklist provided in Method 2

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