UNDERSTANDING THE TECHNICAL CONTENT OF REQUIREMENTS IN SPECIFICATION DOCUMENTS

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Designing a good specification is essential as it contributes to a better overall design. A good design is possible if design problems are clearly defined, which in practice these problems are described in a specification. Thus, support to assist design engineers, during the specification development process, is essential to be devised in advance. To achieve this aim, understanding how to formulate a good requirement is necessary and it is only possible if design engineers understand the technical content of a requirement. In aiming to understand the technical content of a requirement in practice, 97 statements from 2 specification documents were analyzed in detail and the results are reported in this paper. These statements were analyzed quantitatively and qualitatively based on a pre-defined coding scheme. The results of the study show that the majority of requirements were related to the characteristic attributes of the products. The study also found that the solution requirement was a part of the requirements in a specification document. Meanwhile, the issue and class of the requirement are related to each other and several classes of requirement are always required to address a single issue. Furthermore, design engineer needs to consider several related issues in order to formulate a requirement statement.

Keywords: Specification, Requirement, Design Process, Designing.

1. INTRODUCTION

Designing a good specification should be addressed at the beginning of the design process because it contributes to a better overall design. A good specification document is always reflected by the quality of requirements, because the main elements in a specification are the requirements. Through the task clarification process, the stakeholders' needs, which are in the form of customer language, are transformed into engineering terms for the designing tasks. Methods such as quality function deployment (QFD) are usually employed at this stage. These requirements will later on form a base for design engineers to execute the design task. However, the requirements established by the planning group usually leave a large design space for the design engineers.

However, in the case of a customer order, for a specific one-off or small batch product, there are usually tighter quantitative requirements to fulfil. Sudin *et al.* [1] found the customer/client's specification can be classified into three different forms; verbal, semi-developed or full specification. In addition they found in the majority of the cases that the client usually provides semi-developed specification to the company in which the design process will be carried out. In both cases either the specification is developed in-house or outside of the company, design engineers are always required to develop the specification into more detail and rely upon the knowledge and experiences of the design engineers. Thus, providing design engineers with a simple method to analysis an existing requirement that was provided to them and refining it into more detail and clear requirement becomes essential in this context. Before a good requirement can be specified, relevant issues need to be identified,

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considered and understood. Thus this study aims to enhance the understanding of the issues that design engineers consider, while specifying a requirement and identifying the class of requirements that were listed in a specification.

2. LITERATURE REVIEW

The word 'requirement' may have several different meanings. Rios *et al.* [2] define a requirement as a single, unique and unambiguous statement in natural language of a single 'what' (non-functional) or 'function' that some classes of user, stakeholder or client wants, written in a way that it can be ranked, validated, traced, measured, and verified. Eder [3] defines 'a requirement' as a condition or constraint on a transformation process or technical system in its 'as should be' state. Furthermore, he states that 'a condition' is a thing or statement that must be fulfilled if another thing or statement is to be fulfilled; meanwhile 'a constraint' is a thing or statement restricting or forcibly preventing another thing or statement. Ulrich and Eppinger [4] define that 'a specification' consists of a metric and a value. The design and requirement is coupled because, in practice the intended properties of the design, when put in use are stated as a requirement list.

A requirement in a specification belongs to a problem domain, because it defines the design problem.

The terms "requirement" and "specification" are always interchangeable and used by different authors to refer to the same things.

Ullman [5] classified them into: (1) functional performance requirement, (2) human factor requirement, (3) physical requirement, (4) reliability requirement, (5) lifecycle concern requirement, (6) resource concern requirement, and (7) manufacturing requirement. Salonen *et al*. [6] classified requirements into seven classes: (1) requirement related to feasibility, (2) technical requirement, (3) requirement related to size and appearance, (4) requirement for manufacturing and assembly, (5) requirement related to installation and use, (6) requirement for service and, (7) requirement related to lifecycle. Requirements are also classified based on their importance to the design process. A requirement is stated either as a demand or wish. A demand is an objective that any design proposal must necessarily meet. Meanwhile objectives that are not essential in this sense are called wishes. Demand and wishes play different roles in the evaluation of the design [7]. Hansen and Andreasen [8] acknowledge the roles of demand and wishes during the product development process. They state that, demand will differentiate between solution and non-solution, whereas, wishes will differentiate between a good and not good solution. To acknowledge the requirement in the development process, Gero and Kannengiesser [9] stated that, formulation is an important process in conceptual designing, as it specifies an initial design state space, within which, the design solution is searched.

The theory of properties states that; a machine or mechanical product is defined by its basic properties: the structure of the whole product, the form, materials, dimensions, surface and tolerances of the individual elements [10].

Roozenburg and Eekels [11] proposed a procedure for making a design specification. The procedure is comprised of three phases that are: listing objectives, analyzing of objectives and editing objectives. In order to achieve a complete collection of objectives and to minimize the chances of missing relevant objectives, they referred to a checklist comprised of three major elements that were: the stakeholder, the aspects and the product life cycle.

This review provides some overview about specification documents and requirements. Several methods have been suggested to develop a specification. Additionally, some criteria of good requirements and specification have been suggested by a few authors. All these suggestion are beneficial to check the quality of requirements after it was specified. However the fundamental element, i.e. 'the issues' that design engineers think in order to derive a good requirement was not highlighted.

3. RESEARCH AIMS AND QUESTIONS

The final aim of this study is to devise a model and method to support requirement formulation. This study aims to understand the relationship between issues and requirements a specification document.

These include, understanding the issues that design engineers considered in formulating a requirement and identifying the class of requirement specified to address the issue. As a result, the research has two main questions that are:

1. What issues are considered to formulate a requirement specification?
2. How are these issues addressed in a specification?

4. RESEARCH METHOD

Two sets of specification documents were analyzed quantitatively and qualitatively. Each document was developed by two different design engineers in a consultancy company. These documents were the final version of specification documents before the design process was to begin. These specification documents were developed for two electro-mechanical design projects, which were customized projects. The general contents of the specification documents were analyzed and summarized in Table 1. The document title of both projects were renamed to Project A and Project B for confidentiality purposes. The requirement statements vary in length, ranging from 3–100 words in Project A and 1–20 words for Project B. Seventy five (75) statements were specified in Project A and twenty two (22) statements were specified in Project B. Initially, the statements were segregated either as a requirement or a non-requirement. To carry out this process the following definition was adopted in this study. '*A requirement can include a statement about the desired property, attribute, condition or constraint of product to be designed*'. Statements without functional objectives or desirable attributes were classified as non-requirement. However, in this study, non-requirement was considered as a part of the class of requirement instead and included in the results. Finally, the technical contents of 84 requirement statements in both specification documents were analyzed in detail and the results of the analysis were reported in this paper.

Thus, the requirement statements are the object of this study. The technical contents of requirement statements were indexed against a pre-defined coding scheme. This coding scheme was developed based on theory and partially from what emerged during the analysis process. In this study, the requirements were classified into different classes based on the issue that the requirement was concern with; i.e. *physical requirement is concerned with the physical properties of the product i.e. material, dimension, colour, weight, etc.*

5. RESULTS AND DISCUSSION

In this section, the study results are presented based on the following themes: Classes of requirement and the relationship between issues and classes of requirement within a specification. For ease of understanding, the analysis results are presented separately for Project A and B, throughout this section.

5.1. Classes of requirement in a specification

The analysis began by segregating the statements into requirements or non-requirements. In total, there were 75 statements in the specification document for Project A. The study found that only 64 (75%) of them were requirements and 11 (15%) of them were non-requirements. The study investigated

Table 1. Summary of specification documents for both projects.

Document title/ identification		No. of pages	No. of statements in a specification	No. of words in a requirement	No. of Figures/ Tables	No. of revisions
Project A	Basic specification	4	75	1–20	3	3
Project B	Product specification. Project no. 7570	6	22	3–100	6	2

these requirements further detailing and classifying them into different classes of requirement. These classes of requirement were derived from theory and emerged during the analysis process. Ten classes of requirement were stated in the specification document for Project A. These requirements were classified into three main classes. These requirements were:

- Requirements related to product attributes: *performance, physical, material, form, structural, and law- conformance and protection requirements.*
- Requirements related to man-machine interface: *ergonomic, safety, use and operation requirements.*
- Requirements related to the product life cycle: *maintenance.*

The results of the study show that the majority of requirements in the specification were related to the product attributes *i.e. physical, material, structural, performance and form requirements*. In total, these requirements represented 46% of the total requirements in the specification document for Project A. The five main requirements stated were: *performance,* which represented 17% of the total number of requirements, followed by *physical* at (15%), *form* (shape) at (12%) and the *use* requirement (12%). Detailed distributions of the classes of requirement for project A are shown in Table 2. It was found that a functional requirement was not explicitly defined in the specification document; however the solution requirement was part of the requirements in the specification. In this study, the statements that only consider issues e.g. the issue of material, robustness, etc. was not recognized as a requirement and was indexed as non-requirement. The results also show that not all issues require consideration and addressing as requirements. Some issues that were not highly relevant to the design were excluded from the specification document. The decisions to either consider an issue or not, were proposed in the Pugh's checklist [12]. The results also reveal that the solution requirement was a part of the requirements in the specification. This result was in disagreement to some of the literature in design methodology i.e. [4] and continue to paragraph with which emphasise that a requirement should be solution independent, or stated as a solution-neutral statement. It also showed that attempting to derive requirements, without thinking about the solution, may not always occur in practice. Therefore, to imagine the solution, while deriving requirements, could be a good technique for specifying requirements, but ideally it should be stated as a solution-neutral statement in a specification to avoid bias. Even though the solution is requested by the customer, design engineers need to investigate the reasons behind this solution preference before the decision to include it in the specification is made.

The study investigated the specification statements for Project B. In total, there were 22 statements in the specification document for Project B. The study found that only 20 (91%) of them were requirements and 2 (9%) of them were non-requirements. The study found eight classes of requirements stated in the specification document for Project B. Six of them were similar to requirements in Project A, as shown in Table 3. Two new requirements specified (in comparison to Project A) were: Operation and form requirement.

Table 2. Classes of requirement for Project A.

No.	Class of Requirement	No. of statement	Percentage of requirement (%)
1	Performance requirement	13	17
2	Non-requirement	11	15
3	Physical requirement	10	13
4	Form (shape) requirement	9	12
5	Use requirement	9	12
6	Solution requirement	8	11
7	Ergonomic requirement	8	11
8	Protection requirement	3	4
9	Structural requirement	2	3
10	Material requirement	1	1
11	Law conformance requirement	1	1
	Total	75	100%

Table 3. Classes of requirement for Project B.

No.	Class of Requirement	No. of statement	Percentage of requirement (%)
1	Physical requirement	6	27
2	Use requirement	4	18
3	Structure requirement	3	14
4	Solution requirement	3	14
5	Non-requirement	2	9
6	Maintenance requirement	1	5
7	Performance requirement	1	5
8	Form requirement	1	5
9	Operation requirement	1	5
	Total	22	100%

Physical requirement which, was the major requirement in Project B, represented to 27% of the total requirements. The study also found requirements that were related to product attributes i.e. *structure, physical, form and performance requirements* as the dominant requirement, and represented 41% of the total requirements. These results are similar to the results of Project A. The study also found that the solution requirement is also a part of the types of requirement in Project B, and these requirements formed 14% respectively, of the total requirements in Project B.

With reflection to both projects, it was obvious that a non-requirement i.e. should not be in a specification document because it would not direct design engineers for the solution synthesis.

5.2. Relationship between issues and classes of requirement

The study investigates the issues considered by design engineers to formulate requirements. The 'issue' is defined as consideration made by the design engineers to formulate a requirement. In this study the main issues considered counted directly from the specification, were stated as 'subject' as its name in the specification documents (standard format in the case study company). The study found fourteen main issues that were considered by designer engineers in Project A in order to formulate the requirements in the specification. The fourteen issues were: dimensions, weight, modularity, mechanical parts, electrical parts, man-machine interfaces, repair & service, performance, airflow, condensation, insulation, robustness and type of interface, as shown in the second column of Figure 1. To understand the relationship between issues and classes of requirement, the matrix of issued considered/classes of requirement was created, as in Figure 1.

These issues were classified into two types:

- Issues related to *external properties* [3] *i.e. robustness, environment, performance, repair & service, man-machine interface, etc.*
- Issues related to *internal properties* [3] *i.e. mechanical parts, electrical part, air flow, insulation, interface, weight, overall dimension, shape, etc*.

The results show, that several classes of requirements were specified for each issue, with the exception of dimension, weight and interface issues. The maximum number, in the cell of each issue, indicates the number of classes of requirements specified. For instance, the maximum classes of requirements specified for a single issue was eight, which occurred when the design engineer considered issues for mechanical parts. These requirements were; protection, performance, and unspecified specifications (in this case, another issue was considered beside the robustness issue *e.g. robustness was the main issue, then the storage issue was considered without any statement of requirement*). Four for electrical part issues, three for robustness, condensation, performance and man-machine interface, two for airflow and service & repair issues and only one for dimensions, modularity, types of interfaces, environmental condition, insulation between hot and cool area and weight issues. Some of the issues

	Main Issues Considered/Class of Requirement Matrix	Physical requirement	Structural requirement	Non-requirement	Performance requirement	Use requirement	Form requirement	Solution requirement	Material requirement	Ergonomic requirement	Protection requirement	Law conformance requirement
1.	Dimension	1										
2.	Weight	1										
3.	Modularity between S,M and L product		1									
4.	Mechanical parts ((Standard and fabricated part)	1		2	3	4	5	6	7	8		
5.	Electrical parts	1	2				3	4				
6.	Man-Machine interface			1		2				3		
7.	Repair & service									1	2	
8.	Performance of the system			1	2							3
9.	Airflow	1					2					
10.	Condensation and liquid from product			1	2			3				
11.	Insulation between hot and cold area			1								
12.	Robustness			1	2						3	
13.	Environmental condition					1						
14.	Type of interface	1										

Figure 1. Issues considered/type of requirement matrix: Project A.

considered have direct relationships to classes of requirement *e.g. the issue of dimension and weight is addressed by the physical requirements and the man-machine interface issue is addressed by use and ergonomic requirements*. In addition, some issues and classes of requirements were indirectly related to classes of requirement *e.g. the repair & service issue is addressed by ergonomic and protection requirements*. This occurred because the design engineer may have considered other related issues besides the main one. For instance, as observed in the specification document in Project A, the design engineer considers several related issues, *i.e. repair & service issues—ergonomic issues —protection issues*, but the second and third level of issues are addressed through the requirements in a specification. Some issues are difficult to address directly in a specification i.e. *issues regarding robustness*, because this issue is regarded as the behaviour of the product, which can only be observed when the product is in use. Therefore, this issue can only be addressed as an intended performance, through the *performance requirement*.

Based on the results shown in Figure 2, twenty two issues were considered by the design engineer in order to formulate the requirements in a specification for Project B. All the requirements specified were related to the *internal properties* of the product. Since the issues considered are specific to the *internal properties*, the connectivity matrix between considered issues/classes of requirement shows that each issue is addressed only by a single class of requirement. This result shows the similarity between projects A and B, in which issues that are related to *internal properties* of the product are addressed by a single class of requirement. Meanwhile, issues that are related to *external properties* are addressed by more than one single class of requirement. The study also observed that in both cases, the design engineer prefers to list the issues and then specify the requirements that are related to the issue.

	Main Issues Considered/Class of Requirement Matrix	Structure requirement	Physical requirement	Non- requirement	Maintenance requirement	Operation requirement	Use requirement	Performance requirement	Solution requirement	Form requirement	Solution requirement	Protection requirement
1.	Concept and drive system	1										
2.	Angle between parts		1									
3.	Distance between parts		1									
4.	Tolerance for part X		1									
5.	Tolerance between rotational/angular displacement			1								
6.	Tolerance between axial/radial displacement			1								
7.	Rotational patterns					1						
8.	Mechanical design	1										
9.	Power supply						1					
10.	Motor control system							1				
11.	Vibration						1					
12.	Sensor								1			
13.	Lubrication				1							
14.	Bearing	1										
15.	Operating condition						1					
16.	Temperature range						1					
17.	Humidity							1				
18.	Gear ratio		1									
19.	Housing for motor									1		
20.	Material								1			
21.	Surface treatment											1
22.	Test rack	1										

Figure 2. Issues considered/type of requirement matrix: Project B.

6. CONCLUDING REMARKS

To formulate a good specification, it is necessary for design engineers to consider issues. To ensure the whole spectrum of issues are considered prior to the specification development a comprehensive list of issues needs to be formulated in advance. These issues should include the issue that is related to both the *external and internal properties* of the product. The study found some requirements in a specification are included after design engineers have considered several related issues and many of the issues that have been considered need to be addressed by several classes of requirement. The study also found solution requirement is one of the classes of requirement. Therefore, determining the solution as a requirement could be practical in certain situations, *i.e. decided by the client*. Some statements in a specification are not a requirement because they do not specify the stakeholders' needs, but state general issues. A full spectrum of the issues needs to be considered during the specification development. However, the decision either to determine these issues as a requirement in a specification, relies on the design engineers. In addition relationships between issues need to be understood thoroughly to produce comprehensive requirements for a specification. The requirements taxonomy maybe essential for the uniformity of the requirement statement in order to helps different actors in the product development process, to understand the requirement statement. Due to limited number of specification document analyse, with the total number of requirement statements is only 84, thus the generalisation on what issues and how these issues were considered for requirement formulation may not possible. However the results of the study provide an initial step to build a comprehensive list of issues and give a general idea of how these issues should be considered for requirement formulation. Thus, investigating more specification documents maybe essential to generalise the topic of studied. In addition, the relationship between issues considered and class of requirement served as a basis for the investigation of how 'the issues' should be structured prior to requirement formulation may help to devise a required support as mentioned in the section 3.

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