

CHANGE IN REQUIREMENTS DURING THE DESIGN PROCESS

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ABSTRACT

Specification is an integral part of the product development process. Frequently, more than a single version of a specification is produced due to changes in requirements. These changes are often necessary to ensure the scope of the design problem is as clear as possible. However, the negative effects of such changes include an increase in lead-time and cost. Thus, support to mitigate change in requirements is essential. A thorough understanding of the nature of changes in requirements is essential before a method or tool to mitigate these changes can be proposed. Therefore, a case study approach was employed to understand change in requirements during the design process - particularly concerning the initiation, management and decision factors of these changes. Semi-structured interviews were adopted as the data collection method. The interviews were transcribed and analysed based on a pre-defined coding scheme. The results of the study shows that change in requirement was a normal part in the design process because internal stakeholders initiate changes through analysis and evaluation activities, meanwhile external stakeholders were requested changes during the meeting with consultant. All communications between consultant and clients for change requests mostly through informal methods i.e. email or memo. In addition it was found that design engineers frequently updating specification document at the end of the design process.

Key words: specification, change in requirement, design process

1 INTRODUCTION

Specification is an integral part of the product development process. The initiation of a design project begins in one of the following circumstances: 1) the client approaches the company with a basic product idea and only verbal requirements about the product are available; 2) the client approaches the company with a clear product idea and a semi-developed specification of the product is available. However, further effort is required to develop the full specification; or 3) the client approaches the company with a fully developed product idea that they want, and thus, the client provides the full specification to the company and no further specification development is required [Sudin *et al.* 2010]. In the first two circumstances, the client and the company have to go through extensive negotiations and clarification before a *mutually acceptable specification* document can be formulated. In this research, the term '*initial specification*' is used for a *mutually acceptable specification*. In general, the content of this specification focuses on the client's requirements, which are only adequate to initiate the solution synthesis activity. In the third circumstance, design engineers execute designing activities focusing on fulfilling all the requirements that were written in a specification.

Upon receiving the *initial specification*, design engineers aim to develop feasible solutions. In some cases, design engineers prefer to carry out further analysis on this specification, in order to retrieve more information, before developing solutions. However, this approach to design relies heavily upon the strategy of the individual design engineers. Regardless of the designers' strategies, the evaluation of solutions is constituted during the design process. This activity is based primarily upon the requirements in a specification, i.e. a checklist [Pahl and Beitz 1996] comprising of criteria to evaluate solutions during the design phase. As a result of an evaluation activity, an existing solution may be refined or the best solution may be selected, from several concepts. To support the evaluation activity design, engineers sometimes added new requirements into the specification (requirements evolve). In this study, the term 'requirement evolves' is referred to as a *change in requirement*. Adding of new requirements may be due to design decisions made, for instance, to connect two selected function carriers or to compensate for negative consequences of selecting a particular design solution [Svendsen and Hansen 1993]. Nidamarti *et al.* [1997] referred to these requirements as *solution specific requirements*. Synthesis and evaluation activities occur repeatedly during the design process

until the final solution is determined. Cross [1997] found that in practice, original design proceeds by oscillating between sub-solution and sub-problem areas, as well as by decomposing the problem and recombining the sub-solution, where the partial models of the problem and its solution, are constructed side-by-side. In addition, [Chakrabarti *et al.* 2004] found that requirements co-evolve with the solution during design. Changes were classified in several ways. Costa and Sobek [2003] delineate the notion of changes based on their causes. They classified them into three types: 1) changes caused by an error, 2) changes caused by a spiral development (iteration) at increasingly greater levels of design solution fidelity, and 3) changes caused by changes in the problems scope. Changes have positive impacts, i.e. product improvement and negative impacts, i.e. increase in lead-time increase or cost. Thus, changes can be addressed in two ways: 1) through management of changes, or 2) by mitigating the number of changes. Thus, Costa and Sobek [2009] suggest that the change caused by spiral development and change in problem scope could be addressed through better management of changes. However, the authors argue and believe that changes can also be reduced through an appropriate design support i.e. support to facilitate the development of requirements. Nevertheless, before an appropriate support can be devised, a thorough investigation regarding the change in requirements, particularly about its occurrence in the real design situation, is essential. Consequently, this research aims to understand how change in requirements carried out during the design process by interviewing design engineers in practice. The signification of this research focuses on the understanding of the relationship between the three elements; requirement-designing-a specification in practice - and how that understanding can be used to support design engineers to carry out the specification development process.

2 BACKGROUND

Researches relevant to understanding change in requirements, are reviewed in this section, They including specification, designing and change in requirements. This review aims to understand the relationship between these elements in order to form a basis for this study.

2.1 Significance of Specifications during the Design Process

A specification is a document that holds statements of needs for the product to be designed. These statements are written in a specification as a set of requirements. Regardless the type of product e.g. a customised product, technology push, etc., a specification for a design project is always developed prior to the conceptual design phase. Prior development of a specification is essential to ensure that all synthesis activity maintains the desired direction. Embarking on the design project, without accurate and sufficient requirements in a specification, increases the likelihood of a diversion from the original intention of the product being designed [Lock 1968] in [Oakley and Pawar 1983]. Moreover, research shows that flaws in specifications lead to a poor design, but a good specification does not necessarily produce a good design [Oakley and Pawar 1983]. Therefore, designing a good specification is essential to ensure that the cause of design flaws, are at least not due to a poor specification. An empirical study showed that strong focus on requirements is seen as essential for the creation of good products [Almefelt 2005]. However, a too forceful and formalistic strive to fulfill them, may result in sub-optimization or project stagnation, since requirements in practice are often incomplete or conflicting. In general, a specification provides a direction for the process of generating solutions, and provides the normative information for the evaluation [Roozenburg and Eekels 1995].

2.2 Research on Designing

An engineering design process, as prescribed in design methodology literatures, i.e. [Pahl and Beitz 1996; Ulrich and Eppinger 2000; Pugh 1997], generally consists of a sequence of sub-problems, which are refined through different activities, such as task clarification and conceptual design. In practice, the design process is not linear, where the problems are completely defined at the beginning and the design solution is directly derived from them. Several studies have been conducted into the understanding of design. For instance, Dorst and Dijkhuis [1995] compared two paradigms to observe design activities in order to describe the industrial design process. The two paradigms were design as a rational problem solving process and design, as a process of reflection-in-action. The problem solving approach treats design as a search process, in which, the scope of the steps taken towards a solution is limited by the information processing capacity, of the acting subject. Ideally, the problem definition is stable, and defines the 'solution space' that must be surveyed. Whereas the reflection-in-action

approach, i.e. design as a reflective conversation with the situation, problems are actively set or 'framed' by designers, who take action (make 'moves') improving the (perceived) current situation. In conclusion, they describe design as a rational problem solving process and are particularly suitable in situations where the problem is clear-cut, and the designers have strategies that he/she can follow while solving them. Describing design as a process of reflection-in-action, works particularly well in the conceptual stage of the design process, where the designer has no standard strategies to follow and is instead proposing and trying out different problem/solution structures.

2.2 Changes in Specification

A specification is a dynamic document and subjected to changes during the design process. Specifications are changed due to changes made to its core element - the requirements. Specification or Product Design Specification (PDS) is dynamic rather than static. It must be considered as an evolutionary, comprehensively written document, which upon completion of the design activity, has itself evolved to match the characteristics of the final product [Pugh 1997]. The dynamics of a specification is supported by an empirical study, focusing on requirements in an automotive manufacturing company [Almefelt 2005]. Almefelt [2005] stated that, individual requirements are often not static throughout the project, but rather changed, in one or more steps. Gero and Kannengiesser [2004] outlined the reformulation type for addressing change during the design stage. They decompose change reformulation into three levels: the structure level, the behaviour level and the functional level. However, empirical studies carried out by [McNeill *et al.* 1998] confirmed that the reformulation at the structure level is the predominant type of reformulation, during the design course. The same study also discovered that reformulation occurs at both the behaviour and the functional level, but decreases during the design process. Customers may sometimes not be clear on what they want and therefore, their requirements may be underspecified and subjected to changes later on [Hintersteiner 2000].

During the early stages of a project, it is not always possible to make precise statements in the requirement list, as statements have to be amended or corrected during the design and development process [Pahl and Beitz 1996]. In engineering design, the purpose of the design requirement and evolution process is to arrive at a complete, concise and correct description of the design need, expressed essentially in natural language. From this description, a successful design can result [Darlington and Culley 2002]. Design requirements can never be completed - designer engineers must establish requirements for additional technical system properties, which are intended to solve a design task [Hubka and Eder 1988]. The result of a case study, found that two difficulties faced by design engineers during task clarification were: 1) the customer changed the requirements and; 2) the requirements were formulated too late [Romer *et al.* 2001]. The design of the problem and the solution progress feed off each other through continuous evaluation of on-going solutions. Thus, the problem description will evolve during the design process with greater detail or by being changed [Shon 1983]) in [Brissaud *et al.* 2003].

The review of the three elements; specification, designing and change in requirement provide an overview of the implicit relationship between these elements. How these elements affected each others may provide an important feedback to design engineers to develop a good specification. Thus further study of the relationship between these elements in practice is essential to be explored. In this research, the term of 'specification' is referred to a document consisting of requirements and 'requirement' is referred to expression of need that was written in a specification.

3 RESEARCH AIMS AND QUESTIONS

The long-term aim of this study is to facilitate design engineers in developing a good specification in early phase of the product development process. Thus the objective of this research is to understand how changes in requirement carried out during the design process. This understanding including: initiation and management of changes and; factors for change occurrence and decision. Therefore, this research aims to find the answer to the following questions:

- How are requirements change occurred and managed during the design process?
- What are the motivations and decision factors for the requirement changes?

4 METHODOLOGY

In this section, the case study, data collection method and data analysis method that was employed in this research is explained in more detail.

4.1 Case Study

The study was carried out in a consultancy company working in product development. This company was selected due to their involvement in the development of different types of products (i.e., mechanical, electronic and electro-mechanical), projects (i.e., product development, design review, etc.), dealing with different types of clients and at different stages of a project. These situations provided a bounty of knowledge to design engineers. Interviews were carried out with product development consultants to understand requirement changes during the design process. In total, six interviews were carried out and each interview was approximately 40 to 60 minutes long. The interviews were audio recorded and then transcribed. The interviews were semi-structured and throughout each interview session, participants were asked based on the list of questions. Clarification of questions was carried out when necessary i.e. upon the participants' request. The participants gave their responses to the questions; however, they were allowed to expand the discussion, within the scope of the topic, such as with regard to the design itself to provide some examples to their answers. There were also situations where the questions were rephrased into directive questions, instead of originally open-ended questions. For example, the question, "how did a design project begin?" was rephrased for clarity into a directive question as follows, 'how did your client approach your company for a design project?' The participants working experience ranged from 6 to 30 years and their ages ranged from 32 to 55 years old. Each participant gave their response based on different projects that they have been involved with in the consultancy company. The summary of participants and clients is shown in Table 1.

4.2 Data Analysis Method

The interviews transcriptions were indexed against a pre-defined coding scheme. The coding scheme was developed based on theory; however this was expanded upon with codes that emerged during the analysis process. The transcription was parsed into small units called segments. The purpose of segmentation was to facilitate the analysis because the pre-defined code applied only to a single segment. In total, the transcription was divided into 640 segments and each segment varied in length from 1 to 20 words. The results of the analysis were mainly qualitative, and quantitative values were used as an indicator of occurrence. Qualitative analysis was carried out, through thorough examination of texts and analyzing of the relationships between quantitative results.

Table 1 List of products and clients for each participant in the case study company, B2C (business to customer), B2B (business to business)

Participant (Product Development Consultant)	Type of Clients	Products	Type of Business
Engineer A	Healthcare company	Medical device	B2C
	Consumer electronic company	Audio visual product	B2C
Engineer B	Consumer electronic company	Audio visual product	B2C
	Research organisation	Sustainable energy equipments	B2B
Engineer C	Valve and fluid handling component manufacturer	Industrial automation product	B2B
	Oil drilling equipment supplier	Mechanism design, mechanical sub-system	B2B
Engineer D	Healthcare consultant	Medical devices	B2C
Engineer E	Healthcare company	Medical devices	B2C
	Service and solution company in security, avionic system	Security system, avionic system	B2B
Engineer F	Valve and fluid handling component manufacturer	Industrial automation product	B2B

5 RESULTS AND DISCUSSION

The research results are presented in this section and are grouped into three themes: initiation of changes, discovery of changes and sources of motivation of changes. The results are presented based on the consultants' viewpoint.

5.1 Initiation and management of change in requirements

The interviews were carried out to understand the initiation of changes in requirement during the design process. The study found that the change in requirements was initiated either by:

- *Internal stakeholder*: i.e., design engineers in the project team, design engineers outside the project team-12 instances (number of mention).
- *External stakeholder*: i.e., the client (production engineers or marketing and quality engineers in the client's company)-10 instances.

The results show that both internal and external stakeholders were active in initiating changes in requirement during the design process. However the interpretation of the results was influenced a great deal by the set-up of a company, for instance the term of *internal stakeholders* (including production engineers, quality engineers, marketing personal) in the context of manufacturing company may be seen as *external stakeholders* from product development consultants' viewpoint.

In practice, the involvement of external stakeholders during the early phases of the design process was considerably active. However, external stakeholder involvement should be encouraged as early as possible i.e., during the specifications development. This is to ensure that more requirements may be identified, for instance, requirements regarding to the stakeholders' needs. The study found the response (including request for requirement changes) from client mostly receives during the consultant-client meeting (formal meeting) or through informal communication i.e. email, memo, etc. Internal stakeholders most frequently discover the need for a change while carrying out two activities namely:

- *Analysis of problem*: i.e., functional decomposition, imposing constraint, criteria set-up, requirement rationale, etc.
- *Evaluation of on-going solution*: i.e., calculation, simulation, prototype, solution rationale, etc.

Analysis of problem always resulted to requirements change but however leading to a more concrete requirement. Almost similar findings discovered in a separate study carried out by Romer *et al.* [Romer *et al.* 2001]. They found that 84% of the design engineers analysed the requirements before developing solutions, whereas the remaining 16% began with solution development and subsequently deduced the requirements of the product.

It was found that design engineers employed several techniques such as functional decomposition, imposing constraint or requirement rationale for problem analysis, whereas simulation and prototype was used for solution evaluation. This result highlighted an essential need for design support, to assist design engineer in problem analysis during the early phases of the design process. In addition it was found that requirement changes during the design process were not recorded in specification document immediately after a change was implemented. Mostly the requests of requirement changes from external stakeholder were kept in file as a separate document e.g. note, memo, printed email. The specification document was only update (update the requirement changes) once the design process completed, however it is likely dependent to the responsible engineers.

5.2 Factors and decision for requirement changes

The study found two major flaws of requirement either requirement being over specified or not specified. Under and over specified requirements always lead to under and over designed product, respectively. On the other hand, the not specified requirements, may lead to not fulfilling the stakeholders' needs. However, amongst these flaws, incorrect requirements can be most dangerous as it may lead to the product failing in the market and resulting in the products inability to solve the intended problem, as required by the stakeholders. Thus, avoiding this flaw is more essential than the other one. This result highlighted the difficulty to estimate the exact value of design parameters in early of the design process. Change requests during the design process are informal and lack a standard procedure. Decision of requirement flaws was made based upon problem analysis activity. Immediate changes to requirement will be carried out if requirements flaw were found.

To evaluate the on-going solution design engineers always refer back to requirements that the on-going solution suppose to fulfill. Decision either to change the respective requirement or solution will be made and any changes to on-going solution (without changes the initial requirements) will be carried out without consulting client but client was always consulted in advance if change to initial requirements is necessary. In general, changes in requirement occurs in both domains; problem and solution domain, during the design process. Changes in requirement at this design stage mainly aim to update specification to become more concrete as to ensure these requirements are able to navigate design engineers towards an appropriate design solution.

In contrary to rectify requirement flaws, external stakeholders normally requesting requirement changes as to response to external factors e.g. technology progress (6 instances), market demands (17 instances) and customer demands (2 instances) .All these factors are beyond the design engineers control, for instance client may ask for requirement changes for the reason of market expansion or for the latest technology introduced into the market e.g. communication technology, manufacturing technology, etc. The results from the study, reveals that *market demands* was the primary external factor during the design process. This result highlighted the importance of considering market demand, technology update and client preference throughout the design process. Therefore, design engineers must be responsive to these factors, instead of just focusing on fulfilling the existing requirements. It was found that risks as a result of a change were always the main issue discussed in order to make change decision in a collaboration project.

6 DESCRIPTIVE MODEL OF INFORMATION FLOW FOR A CHANGE IN REQUIREMENTS

Figure 1 illustrates the information flow for change in requirements. Despite the informality of the change process, the implicit procedures still exist. As depicted in Figure 4, the process is comprised of; identification of the need of change, change request, change decision and change implementation. In order to make a change decision, it is essential to identify in advance information from the upstream processes (e.g. identifies need and change request) and its information content (e.g. factors, type of flaw, flow of request, approach). This information is related to the decision-making factors considered during the decision process. The model of information for this study is not yet fully comprehensive. Further investigation of the information content for each change process will require additional research.

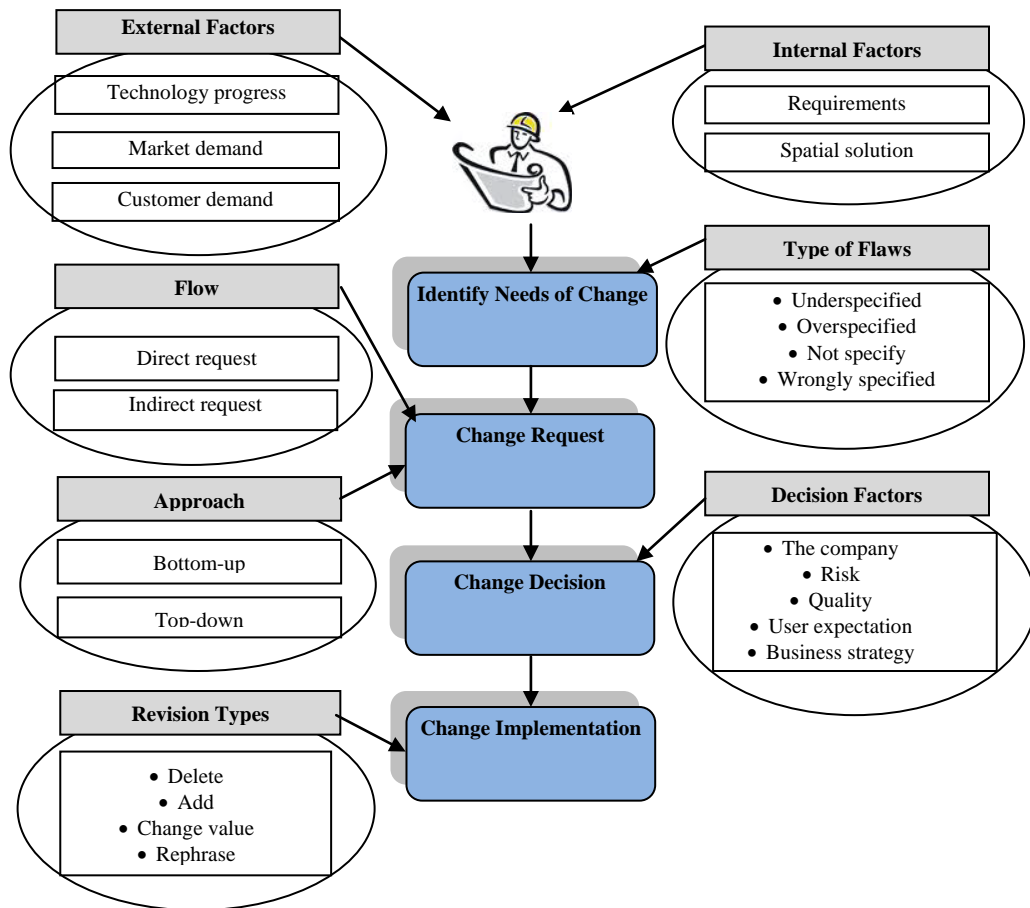


Figure 1 Model of information flow for change in requirements

7 CONCLUSION

The objective of this research is to understand how changes in requirement carried out during the design process. This understanding including: the initiation and management of changes and; the factors for change occurrence. Changes in requirements are part of the design process as it is impossible to completely identify all the requirements during the early phases of the design process.

The mechanism to discover the need to change a requirement, emerges as a result of designing activities i.e., *requirement analysis and solution evaluation*, or from external factors i.e., *technology changes, market demands, customer requests*. Therefore, a balanced consideration between focusing on fulfilling requirements and being responsive to the external factors are an essential part of design practice. Requirement development is part of the process of designing so is a normal activity during concept design phase. This process is referred to co-evolution by several authors i.e. [Cross 1997], between the problem and solution domain. The consequences are not severe for designers working alone on a small product but are expected to lead to a more iterative design process, but it has more serious implication when working as part of design team on a larger, more complex product due to interfaces with other assemblies.

Changes in requirement during the design process are informal (lack a standard procedure) and frequently changes in requirement are carried out without updating the specification. Design engineers are found to update the specification at the end of the design process. Any modification (change) on an initial specification is always carried out upon client approval. Thus changes in requirement that does not modify an initial specification is considering as a normal activity during the design process. In a collaboration project, both internal and external stakeholders are actively involved in initiating changes during the design process.

Understanding all the information content of the upstream process; the change identification and change request process (refer to Figure 1) form an essential input to the change decision process. These decision factors are directly fed back to the information content of the upstream process. For instance, in considering a 'business strategy', input from external factors may be relevant to be considered as well. In general, changes in requirement during the design process were essential as a way to produce more concrete requirements in a specification. Risks due to changes in requirement were the most important aspect discussed by decision makers when deciding to implement the change or not.

Support to facilitate requirement analysis during task clarification seems to be a promising approach to mitigate change in requirement i.e., due to the requirement not being defined or wrongly defined. Even though completely defining requirements at the beginning of the design project is impossible, to reduce the gap i.e. number of changes to requirement between the, *initial specification* and *full specification*, maybe possible. The process of analysing requirements in a specification should be continual, as the design proceeds along the design phase.

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