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Criteria for the Assessment of Representation Methods as Vehicles for Handling Change

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About the author

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Abstract
This paper describes the development of a set of criteria for assessing representation and design methods as vehicles for handling change. The approach taken is to identify a set of common change management problems, to appraise methods of representation for their contribution or resilience to these problems and thereby identify a set of issues on which the criteria are based. Two categories of criteria are developed. Firstly there is a set of criteria that are applicable whatever the context. Secondly there are specific sets of criteria for each of the three strategies employed for reducing the impact of change, namely avoiding change, driving it out early in the lifecycle and facilitating its incorporation.

1. Introduction

However good methods of requirements elicitation become there is always going to be a problem of unstable requirements. Although one of the principal aims of project management is reduction of the risk associated with changing requirements, either by avoiding change or managing it, existing development methods pay little systematic attention to the instability of requirements, and problems associated with changing requirements arise throughout the systems development life-cycle [1,2].

This study is focused on the ways in which current methods of representation and design, which have been developed or adapted to support a traditional, linear lifecycle, handle the uncertainty and change which characterise the reality of system development. The inadequacy of the waterfall model, based on the erroneous assumption that a complete, concise and consistent specification of a proposed system can be produced prior to design and implementation, has long been recognised [3]. Using case studies of actual industrial projects, we have attempted to identify the problems associated with change and the issues regarding its
management and reduction. The end product of this study is a set of criteria by which prospective methods may be assessed for their ability to handle changing requirements.

Although we are focusing on methods of representation and design it is impossible (and undesirable) to attempt to divorce these from the actual design process, so the methods are examined within the context of the process within which they are used. The term representation is used here in the sense of any representation of requirements specifications or design realisations, and the term method is used to mean any method, process, technique or tool.

2. Study methods

This study is part of the Proteus project (a UK DTI/EPSRC SafeIT project entitled 'Understanding Changing Requirements') which aims to examine the origins of the instability of requirements, and to develop criteria for assessing the suitability of approaches to requirements engineering and methods of systems design in order to deal more effectively with instability. The context in which the study was undertaken is that of the development of large-scale, embedded, real-time, safety-critical systems within the aerospace and nuclear industries, and it should be noted that some of our observations are particular to this context.

Due to the nature of this industrial context, where each project is of considerable length, non-concurrent, and in other ways non-comparable with other projects within the same industrial context, it is impossible to acquire precise quantitative data of the gains in process productivity or quality of the eventual product which can be attributed to the adoption of particular methods or tools. A case study approach was therefore adopted, tailored to elicitation of knowledge from a number of expert practitioners with experience of working on several projects using various methods and tools. Several case studies were undertaken in each organisation, the case study method involving face to face interviews, study of the project documentation, and demonstrations and discussion of the methods and tools being used or trialled on the projects. This empirical approach was adopted to ensure that any conclusions reached by the project are well grounded in the real world and are appropriate to the specific organisational context from which they originate.

3. Results of case studies

Change management problems

The first step was to identify change management problems that were common to most of the case study examples. The problems identified are now reviewed briefly.

Requirements engineering process: The requirements engineering process employed on a project imposes constraints on change management and may itself be a major contributor
to the amount of change needed, particularly if the requirements are frozen too early in the life cycle, and if the requirements process results in incomplete or incorrect requirements specifications. An approach where the known requirements are tackled first results in many changes later, that could probably have been avoided had the uncertain areas of requirements and design been resolved early in the life cycle. It is however not always possible to resolve all difficulties and areas of uncertainty before proceeding, and it is necessary to develop a method where the areas of uncertainty can be bounded such that they do not give rise to excessive change as their eventual nature emerges.

**Project management:** Project management is closely allied to the nature of the design process, and as observed in practice it is difficult to separate one from the other, although essentially the design process is a cognitive activity, whereas the project management process is a control and monitoring activity. It is evident that lack of skilled project management and support for project management increases the problems of change management.

**Contracts and contractual boundaries:** Contractual boundaries are a major impediment to the flow of requirements information, so it is important that specifications communicate an understanding of all the information needed to those on either side of the boundary. This property of contractual boundaries applies whether formal contracts exist between separate companies, or whether they are *de facto* boundaries between different departments within an organisation. Contracts must incorporate control and quality assurance, and the basis for this will be the requirements agreed between customer and supplier, or between contractor and sub-contractor. The accuracy and stability of this specification thus assumes a much greater level of importance than it would if it were purely a working document, and many problems arise when the level of a contractual specification is inappropriate. Too open a specification may cause interpretation disputes between customer and supplier, and too detailed a specification is too binding and may give rise to many change requests from both sides of the contractual boundary.

**Change process:** The change process itself was observed to be unwieldy and complicated largely because it was unsupported by any of the methods of representation used. In fact there often appeared to be an informal change procedure where changes were discussed and decisions made, followed (possibly some time later) by the formal process of change control with the creation and authorisation of all the documentation that had to be appended to the appropriate section of the existing design and quality process documentation. Further processes would periodically incorporate the appended changes into the next release of documentation.

**Standards:** Designers in the safety-critical domain are obliged to ensure that their products are certified by the relevant authorities, with conformance to standards as the principal means of assessment. Standards are thus a major constraint on the requirements engineering process and change procedures, as they place particular demands on the documentation recording the design, any changes to the design, and the change control process itself.
Assessment of impact: There is a need to be able to predict and assess the impact of changes and the resulting cost. This activity appeared to be largely unsupported by the methods of representation that we observed, in that there was no simple way of identifying all of the design areas on which a change would impact. Assessments were largely intuitive, based on past experience and personal knowledge of the current design.

Communication: The communication of information through the various stages of the development process, and to the various parties involved in that process, is essential to efficiency. Problems of ineffective communication, including lack of communication of design rationale, contribute to the number of change requests incurred.

Levels of specification: The number of levels of specification used in most projects created problems, and the content in each was not always appropriate for the purpose for which that level of specification was used. In general problems seem to arise from the use of too many levels of specification, resulting in too great an overlap between the design stages. Change appears to be reduced if the level of specification is no lower than necessary at a given stage of the design process. More open specifications, saying 'what' should be done, are preferable to detailed specifications that state in detail 'how' things should be done, particularly as the basis of contracts, in that they appear to reduce the number of change requests. It is however important that the specification should still convey all the necessary information regarding the requirements.

Traceability: Information must be effectively transferred and linked through the various stages of the development process, and the various parties involved in that process. Lack of an effective means of tracing requirements and design rationale, both forward and backwards through the successive levels of representation and within a level, contributes to the number of change requests, makes conformance with the original specification difficult to demonstrate, and makes it more difficult to assess the feasibility of accommodating any change.

Documentation: Paper documentation is the principal method used for representation of the current state of the requirements and design and it brings with it the problems associated with large volumes of documentation. It is a poor means of communicating information between the agents involved in different parts of the process in that the sheer bulk of the documentation makes the process of referencing it time consuming. We have even heard it referred to as 'write only' documentation. The problem is compounded by the fact that diagrammatic representations are usually so specialised that the information they contain is only understandable by the few people conversant with them. Traceability is a cumbersome manual task that is usually only possible between adjacent levels and impact analysis is virtually impossible. Changing paper based documentation is a considerable barrier to change in itself, and also exacerbates the other change management problems identified.
Appraisal of change management properties of representation methods

Having identified a set of common problems we went on to review five basic methods of representation, namely paper documentation, electronic representations, rapid prototyping, simulation and design animation, in order to identify which of their properties had the greatest impact, whether beneficial or detrimental, on the change management process.

We found that methods tend to fall into one of two categories: those that reflect only the current understanding and those that are predictive of the properties the eventual product will exhibit. Methods that reflect only current understanding, especially paper based representations, contribute heavily to the problems listed above. They retard the flow of information, make the change process unwieldy, and provide scant means for the assessment of the impact of change and for traceability. They do not facilitate understanding in the design process; they are unsatisfactory in effectively communicating requirements and design information; they promise benefits in controlling the design process, but create balancing change management problems; they are compliant with current standards; and lastly they are a trusted and well tried method.

Methods that are principally predictive include prototyping, simulation and design animation. At present they are mainly used for representation of requirements to the client and/or user, although some design development may also take place during this process. These methods are being recognised by the organisations using them as being instrumental both in reducing change and in discovering the need for change earlier in the life cycle, thereby substantially reducing development costs. They are being introduced into the development process increasingly for these reasons. The properties which provide these benefits are, we believe, that they support improved understanding of the requirements and the design, because they are very effective communicators. On the other hand, we found that they could not readily be incorporated into current models of project and contract control processes in such a way as to maximise the benefits they offer, largely because of the conservative nature of the organisations studied. Also it is difficult to demonstrate compliance with standards which are oriented towards processes using representations of the type we refer to above as current understanding.

Design animation in particular offers benefits in handling change. It offers the benefits of predictive forms of representation, facilitating understanding and communication between designers and users, supports early testing and early integration resulting in the driving out of changes at an earlier stage, and provides a means of assessing subsequent change and its impact. Because it is not only a predictive representation, but is based on a record of current understanding of the design, it offers many of the advantages of such methods also, especially if it can offer automatic recording of change and version control. As it incorporates a record of current understanding, it should also be compliant with current standards.
4. Criteria for the assessment of methods as vehicles for handling change

From this review of current representation methods and study of the relationship between these and the problems of change management described above, we are now in a position to state the attributes that a method of representation should demonstrate in order firstly to avoid creating change and change management problems, and secondly to overcome the problems that unavoidable change can create. Criteria based on these attributes fall into two distinct categories: global and specific.

Global criteria

The global criteria consist of a set of criteria based on the goals or objectives that all methods should aim to achieve, and also a set of criteria based on constraints imposed by the organisational and use context.

The first goal is to promote understanding of the requirements and design in general, and specifically of the need or potential for change and the consequences of change. This understanding of change will feed into risk analysis and cost/benefit assessments and thereby contribute to the decision making process. Following this is the second goal of supporting action by revealing options, and facilitating the choice of action and its implementation. A method should promote communication to the large number of people and organisations involved in the process; it should provide means of control of the process and its attendant costs and timescales; it should support evaluation in terms of metrics used, the effectiveness of the design solution, and quality assurance of the process and its resultant products. Additionally it should promote organisational learning by means of metrics analysis and history management.

We have also recognised a set of global constraints that should be considered before endorsing a particular method. These are based on standard usability and organisational impact concerns [5]. The goals and constraints criteria are listed in Table 1.

Change criteria

Based on our analysis we have compiled a schematic set of criteria to be applied to prospective methods for assessing their ability to handle change. It is important to recognise that it is the impact of change in terms of cost, time and design integrity that inevitably consumes resources and may create uncertainty and risk. The essential ways in which to handle risk are to identify it (risk analysis), avoid it (risk reduction) and manage it. Similarly, if our goal is to minimise the impact of change, we should aim to identify the need for change, preferably as early as possible in the lifecycle, to avoid or reduce change and to manage change
by facilitating its incorporation. (A fourth strategy as with risk is to transfer it but we are not addressing this here).

We have taken these three basic strategies for the minimisation of the impact of change, and have developed a set of criteria for each strategy, by which methods can be judged for their effectiveness in furthering that particular strategy. These criteria can be regarded as attributes that a method should possess in order to be able to handle change in the chosen way.

These specific criteria embody the global goals criteria in that each specific criterion must satisfy the subset of the global goals that justifies its effectiveness as a strategy for handling change in that way. For example, whether or not a method promotes option generation is a specific criterion for judging whether change might be driven out early. We can evaluate how well the method performs in this respect by checking whether it facilitates communication between designers, users and/or customers, whether it contributes to understanding of the need for and consequences of the change, whether it facilitates evaluation of the options and suchlike. The list of global goals criteria can thus be used as a checklist for evaluating how well the method under consideration meets each criterion against which it is being assessed.

In addition, before endorsing a particular method, it should be evaluated against any of the global constraint criteria that apply within the given context to assess its acceptability within this context.

The sets of criteria that are listed in Table 2 are still under development and will undoubtedly be expanded, but those listed illustrate the basic criteria identified to date.

<table>
<thead>
<tr>
<th>Global goals criteria</th>
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<tbody>
<tr>
<td>Understanding</td>
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<td>of need for change</td>
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<td>of consequences of change</td>
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<tr>
<td>Action</td>
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<td>options</td>
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<tr>
<td>Learning</td>
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<tr>
<td>history</td>
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<td>metrics analysis</td>
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</table>

Global constraints criteria

<table>
<thead>
<tr>
<th>Usability</th>
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<tbody>
<tr>
<td>ease of learning</td>
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<td>ease of use</td>
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<td>efficiency</td>
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<td>user satisfaction</td>
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<td>consistency with other</td>
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<td>tools and methods</td>
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constraints of method

Organisational impact on structure
  on culture - matching
  - inertia
  - acceptability
  on contracts
  on resources - financial
  - human
  - skill base
  - physical
  on integrity
    (including security)

Dependability

Timeliness

**Table 2. Change criteria**

**Criteria for avoiding change**

Completeness of requirements elicitation?
Precision and accuracy of requirements?
Unambiguous representation?
Tight control? - by rigid contracts?
  - by project management?
Contains risk analysis?

**Criteria for identifying change early**

Predictive? - by prototyping?
  - by simulation?
  - by design animation?
Generates options? - by prototyping?
  - by brainstorming?
  - by modelling?
  - other methods?
Concurrent approach? - by interdisciplinary teams?
  - by early integration?
Early evaluation? - by feedback to user?
  - by walk through?
  - by consistency checking?
  - by traceability?

**Criteria for facilitating the incorporation of change**

Flexible design? - part representation possible?
  - through modularity?
  - user configurable?
  - other methods?
Explicit design rationale?
  - includes traceability?
  - records decision history?
  - indicates potential for change?
Self-documenting?
Provides for representation transfer?
  - interfacing?
  - translation?
  - linkage?
Contains impact analysis?
  - prediction of consequences?
Contains risk analysis?

Method for using the criteria

The three strategies for reducing the impact of change will not all be appropriate all of the time. For example it is obviously not appropriate to introduce a method such as rapid prototyping in a project that is almost at the end of its lifecycle. Whether the main strategy is to avoid change, drive it out early or facilitate its incorporation will depend on context, and the assessment of a method should be biased towards using the criteria for the most appropriate strategy. This does not mean that the criteria attached to the other strategies should be ignored but that there should be a bias towards the chosen strategy. The primary contextual factors influencing the choice of strategy for dealing with change are the stage reached in the lifecycle, the degree of system openness, the degree of technology innovation and the relationships between them. These can be represented as a context space as in figure 1. The most change will occur in environments nearest to the top left hand box, that is early in the lifecycle, in an open system and turbulent environment. In these circumstances the ability to incorporate change easily would be essential for the success of a project, and in this case the assessment of a method should be biased towards the criteria supporting this strategy.

The process for using the criteria may thus be summarised as follows:

Step 1. Look at the context and choose the bias to be achieved: whether the aim is to avoid change, drive it out early or facilitate its incorporation. Select the criteria to be used accordingly.

Step 2. Compare the properties of the method being assessed with the selected criteria.

Step 3. Evaluate how well the method meets the criteria by applying the global goals criteria.

Step 4. Cross check against the global constraints.

7. Summary

It is the requirements engineering and design process together with the need for recording of this process to demonstrate compliance with standards that determines to a large extent the process for handling change. It is within this context that we have attempted to identify what attributes specific methods of representation need in order to reduce and manage change in
requirements. These factors can then be taken into account when new methods are being considered.

We approached the problem by first identifying the problems associated with change management that commonly arise during systems development. Keeping the problems that were identified in mind, five common methods of representation were then appraised for their ability to facilitate the management of unavoidable change, and also how they might contribute to reducing change and its impact. We found that representation methods tend either to reflect the current understanding of the design or to be predictive of the eventual behaviour of the product. The contrasting attributes of these two categories led us to the realisation that different sets of criteria are needed depending on whether the immediate aim is to avoid or reduce change, to drive it out early in the lifecycle (one of the objectives of predictive methods) or to facilitate its incorporation.

Underlying these criteria that are aimed specifically at a particular strategy for the minimisation of the impact of change, which is the ultimate goal, is a set of attributes that are global. They include promoting understanding, communication and control, and supporting action, evaluation and organisational learning. It is only through meeting these criteria that a
method can effectively satisfy the specific criteria such as supporting traceability, impact analysis, design flexibility and change control processes.

At present the sets of criteria are still under development, and are being tested on several tools and techniques including RTM, reasoning about formally expressed requirements and rapid throw-away prototyping. These tests should not only help us to evaluate the criteria, but should provide a valuable appraisal of the tools under test.

To end, we can distil from the sets of criteria a picture of the ideal method of representation. It should permit design decisions to be traceable back to the particular concerns of stakeholders and to be transferable across contractual boundaries. The representation should illustrate the links between requirements so that analysis of the possibilities and consequences of change can be made. It should be capable of part-representation where requirements are not yet determined, and of illustrating the potential for change of individual requirements. This should encourage a design which is tolerant to instability in the requirements and has flexibility built into it. Such issues do not appear to be considered in current representational forms. A further consideration is that the method should not only provide a representation of the requirements but also the rationale behind the design, and record the change process as changes are made. This would go a long way towards addressing the problems recognised in our study.

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