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Change Handling Criteria for the Assessment of Requirements and Design Methods

R.C. Sugden and M.R. Strems

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Keywords: Changing requirements, change management, assessment criteria, requirements and design methods

1. Introduction

Although problems associated with changing requirements arise throughout the systems development lifecycle [1,2], existing research efforts [3] and development methods pay little systematic attention to the instability of requirements. 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 [4]. We have approached this problem firstly by examining the way in which current methods and processes, which have been developed or adapted to support a traditional, linear lifecycle, handle the uncertainty and change which characterise the reality of system development. Using case studies of actual industrial projects, we have attempted to identify the problems associated with change and the actions that appear to mitigate these problems most successfully. From this survey we then abstracted the issues that cause problems in handling change and identified the strategies that appear to address these issues most
successfully. The third step was a rationalisation process to produce checklists in the form of sets of criteria. These are intended to be used to assist in determining whether the adoption of a particular strategy for dealing with change will be successful, and whether a particular method has the necessary attributes to fit into the overall process and the context within which that process takes place.

For the sake of brevity the term ‘method’ is used throughout this paper to mean any method, process, technique or tool for requirements engineering and design, unless it is necessary to differentiate between processes, methods and tools, or between requirements engineering and design.

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 for dealing more effectively with instability. The context in which the study is being 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. 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. 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 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.

Our initial attempt at producing sets of criteria was restricted to assessment of methods of representation [5], but we found that the use of representation methods is inextricably bound up with the totality of the requirements and design process. Hence it was felt necessary to produce sets of criteria which could be applied to assess any of the methods and tools adopted by the chosen process and to assess the process itself in its entirety. For this reason the case studies were revisited, the data reviewed from the perspective of process, methods and tools and the sets of criteria restructured and expanded. In addition discussions were held concerning changes to processes and methods that our partner organisations proposed to implement in the future. The rationale behind these changes has particularly fed into the development of the utility, organisational and other contextual criteria.
3. Change management problems

As stated the first step undertaken was to identify change management problems that were common to most of the case study examples. The problems identified are now summarised.

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.

Project management: Lack of skilled project management and lack of support for project management increases the problems of change management.

Contracts and contractual boundaries: Because contractual boundaries are a major impediment to the flow of requirements information, 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. The accuracy and stability of the specification used 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.

Change process: The change process itself was observed to be unwieldy and complicated because it was largely unsupported by any of the methods of representation used. 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.

Standards: Standards, particularly for safety-critical software, are 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 of change: This activity appeared to be virtually unsupported by the methods that we observed. Assessments are largely intuitive, based on past experience and personal knowledge of the current design.

Communication: Problems of ineffective communication through the various stages of the development process, including lack of communication of design rationale, contribute to the number of change requests arising late in the lifecycle.

Levels of specification: Problems arise when the number of levels of specification used and the content of each level are inappropriate, and particularly from the use of too many levels of specification, resulting in too great an overlap between the design stages.

Traceability: Lack of an effective means of tracing requirements and design rationale, both forwards 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: Large volumes of paper documentation are a poor means of communicating information between the agents involved in different parts of the process. Making changes to paper based documentation is
a considerable barrier to change in itself, and also exacerbates the other change management problems identified.

**Representation:** Natural language representations tend to be relatively easy to change in that they are understandable, but they lack accuracy and precision and are unsuitable for showing relationships. The alternatives, diagrammatic and formal representations, overcome these problems but are less amenable to change in that the information they contain is only understandable by the few people conversant with them.

### 4. Approaches to change management

Having identified a set of common problems we went on to review the processes and methods used in the case studies from the viewpoint of change management. We identified a set of procedures for handling change similar to those for handling risk. Firstly there is change assessment consisting of change identification, analysis and prioritisation, and secondly there is change management *per se* consisting of reduction, planning, control, facilitating and monitoring.

Some of these aspects of change management such as change assessment and monitoring are usually separate processes within the overall development process. Others are handled within the main requirements and design methods, and it is these that we are attempting to address from the viewpoint of their ability to minimise the adverse impact of change. Our precise goal can be defined as: 'The minimisation of the adverse impact of change on any aspect of the development project together with the maximisation of the benefits of change'. We recognised that the requirements and design methods reviewed employ a variety of strategies for achieving this goal. These strategies are to identify the need for change as early as possible in the lifecycle (when changes can be made more quickly and cheaply), to facilitate the incorporation of change and to reduce or suppress change. (The transfer of responsibility for implementing change may be considered to be a fourth strategy, but for our purposes we are regarding this as a variant of the last strategy - reducing change).

We must make it clear here that we are not regarding change as a bad thing, since it is often essential to the success of the project. However there will frequently be situations where it can be anticipated that change will have an adverse impact on the project in terms of cost, time or design integrity and may create risk in terms of these and other hazards such as safety and dependability. In these cases the best strategy may be to avoid change if this is possible, or to minimise its impact when it is unavoidable.

### 5. Assessment criteria

In addition to the goal of minimising the adverse impact of change on the project there are several other goals that must be achieved by a successful method. These are concerned with the implementation of the method, the context in which the method is used and the fundamental properties which all methods should possess. In effect these are part of our original goal of minimising the adverse impact of change but recognise that methods are deployed in a wider context.
We have therefore developed sets of criteria that can be used as checklists to assess methods for their ability to achieve these goals. There are four sets: criteria specific to a particular strategy for managing change, utility criteria, context criteria and basic criteria.

**Strategy-specific criteria**

As already stated we have recognised three strategies for minimising the impact of change on a project, and for each strategy we have developed a set of criteria by which methods can be judged for their effectiveness in furthering that particular strategy. These criteria can be regarded as attributes that a method might possess in order to be able to handle change in the chosen way. Another way of describing this is to say that the strategy describes **why** we expect the method to achieve our goal of reducing the impact of change, the criteria describe **what** must be done to meet the strategy, and the method itself is **how** it is done. These criteria are summarised in Table 1.

**Criteria for reducing change**: These criteria are based on several different ways of reducing change. They consider the completeness of the requirements elicitation process in terms of whether all types of requirement, functional, non-functional and organisational, are gathered, and in terms of the methods used such as interviews, ethnographic techniques, scenarios of solution options and suchlike. They ask whether the methods used, such as stepwise refinement, formal methods, models and prototypes, will lead to accurate, precise and unambiguous representation of requirements. Another way of keeping change to a minimum is by maintaining tight control either by means of rigid contracts or by including control procedures within the project management process and enforcing their use.

**Criteria for identifying change early**: These criteria ask whether the method embodies one or more of the many techniques that should lead to early identification of the need for change. These include option generation by means of brainstorming, modelling or prototyping; exploration of requirement and design uncertainty by means of sensitivity analysis; prediction of the behaviour of the system by means of prototyping, simulation and design animation; early evaluation of the system by means of walk throughs, consistency checks and feedback to and from users, customers, collaborators and suppliers; and a concurrent approach based on interdisciplinary teams and/or early integration.

**Criteria for facilitating the incorporation of change**: These criteria cover many different ways in which the making of changes can be facilitated. Firstly there is the means of representation: whether it is capable of partial representation to allow for areas of uncertainty to be dealt with later; whether it can indicate the potential for change, or whether it can handle variants or versions. The transferability of the representation is important in terms of clarity to the people who need to understand it, whether it interfaces to other methods, whether it is translatable for use in other methods and whether it provides linkage to other parts of the design.

Another important way in which the incorporation of change can be facilitated is by making the design rationale explicit. This may be assisted by using a method that provides traceability, or that records decision history or that is self-documenting. Since it is important to be able to predict the consequences of change, methods should incorporate some means of impact analysis and risk assessment and management. Another consideration is whether the method has the flexibility to accommodate change readily by means of change
management procedures, or by the modularity of design, by using object orientated techniques, by having re-
configuration potential or by providing for user configuration.

Utility criteria

These criteria (Table 2) ask whether the method has certain necessary attributes without which its usefulness
would be much reduced, or even negated. Although these criteria could be said to be applicable to any method
we consider it important to restate them in this context as we have observed situations where change handling
has been inadvertently made more difficult by methods that have not fulfilled these criteria.

Usability: Usability can be defined as enabling users to carry out their tasks 'safely, effectively, efficiently,
and enjoyably'. Usability criteria should therefore include ease of learning, ease of use, efficiency, and user
satisfaction and safety [6].

Dependability: The method must be reliable in use, that is users must be confident that it will produce a
correct result, whenever, and however many times, it is used.

Timeliness: This heading includes several criteria: whether the method can produce the required result within
the imposed timescale; whether the method is available for operational use at the appropriate time in the project
lifecycle; whether the method is suitable for the stage reached in the lifecycle.

Compatibility: The method will be difficult or impossible to use if it is not compatible with other tools and
methods being used in conjunction with it. It must also be compatible with the relevant standards.

Scalability: However successful a method might be during trials it will only be suitable for a specific project
if it is usable on the scale of the actual project. It should also be appropriate in terms of not being 'overweight'
for the task in hand.

Context criteria

The context in which a method is used is made up of a number of constraints, all of which are negotiable to a
greater or lesser degree. Consideration of the degree to which influence may be exerted to reshape this context
produces a hierarchy of sub-groups, the inter-organisational context having the widest scope but being the least
easy and least likely to change, the organisation itself also being highly resistant to change, whereas at the
individual project level change is common and relatively easy. These criteria are summarised in Table 3.

The inter-organisational context includes the common culture shared by the organisations involved, the
need to exchange information between organisations, the contractual relationships between the organisation and
its customers, sub-contractors, and partners, and the control imposed by independent regulation and, where
relevant, standards. A method must be acceptable to the common culture and to whatever regulatory bodies are
relevant, it should facilitate exchange of information, and not be precluded by any contractual requirement to
use specific methods.

The organisational context includes the culture of the organisation, its structure (functional, management
and skill-based structure), its objectives (including organisational goals and policies), integrity issues (e.g.
commercial confidentiality, defence security) and organisational timescales such as business cycles and
workflow schedules. These criteria ask to what degree the method is compatible with these properties of the
organisation.
At the project level resources must be available to support use of the method. Financial, physical and human resources must be considered and the availability of the required skills.

**Basic criteria**

The basic criteria (Table 4) cover the fundamental properties of methods in general. We use these criteria from a change-handling viewpoint, but they are described as basic as they can equally well be applied for assessing a method from other viewpoints. These criteria operate as a final, compositionality check, to be applied. The complete set of 'processes, methods and tools for requirements engineering and design', which will make up the complete method extending over the entire product lifecycle, must together (but not necessarily separately) meet all of the basic criteria. However effective each particular part of the process is, problems are bound to arise if all the basic criteria are not met somewhere within the totality of methods used. (It could also be argued that if any of the basic criteria are met by a disproportionate number of the components of the total method, then too much activity is being duplicated, which may cause cost and time lags in dealing with change).

**Understanding:** As well as promoting understanding of the requirements and design in general and of the rationale behind them, a method should promote understanding of the need for change, of the potential for change and of the consequences of change. This understanding of change will feed into design decisions, risk analysis and cost/benefit assessments and thereby contribute to the decision making process.

**Action:** The method should support action by revealing options for action, facilitating the choice of action, and the implementation of the action. A means of assessing the risk of change (and the risk of rejecting the change) is important to inform the decision making process.

**Communication:** The method should promote communication between the diverse people and organisations involved in the process of both understanding and action. It is especially important that the method should communicate information about the need for change to all those who may be affected by that change, before the action for change is undertaken, so that all possible consequences of the change and options for action may be revealed before a course of action is decided. Following the decision on the action for change, it is equally important to communicate the decision to those affected, including an indication of the anticipated consequences of this action.

**Control:** The method should provide means of control of the (change) process and its attendant costs and timescales. This includes controlling the introduction of change into an appropriate stage of the product lifecycle (via change-batching and version control), allocation of responsibility for the cost of change, assessing and recording the cost and time to implement change, management of the perceived risk involved in making a change, and quality assurance of the process(es) involved in dealing with change.

**Evaluation:** The method should support evaluation in terms of the effectiveness of change in satisfying the goals of the stakeholders, and quality assurance of the resultant product.

**Learning:** The method should promote organisational learning about the potential for change and the consequences of change, by means of history management and metrics analysis.
6. Guidelines for using the criteria

To simplify the application of the criteria, and potentially to allow some quantification of what is essentially a qualitative assessment, we have presented the criteria in the form of checklists, but it must be recognised that to apply them as such without understanding the rationale which led to their creation would be to limit their value considerably.

The criteria are presented in an order which seems to be appropriate for their application. The strategy-specific criteria should be considered first, followed by the criteria for utility and context, and finally using the basic criteria to assess the completeness and balance of the overall method.

In studying the problems of dealing with change, we have recognised that some of the difficulties encountered have actually been created by attempts to ameliorate or solve other change-related problems. (A classic example is the drive to document software designs in the belief that this would assist those who subsequently had to apply changes to the software; whilst there are undoubted benefits to be gained from comprehensive and accurate documentation, changing the documentation can now present a greater barrier to change than changing the software itself.) This caveat must be applied also to the application of these criteria. Attempting to fully satisfy all the criteria (if indeed that were possible) would probably result in an unworkable requirements and design process, requiring an unacceptable level of resources. The important issue is to attempt to assess the method against the criteria and then to consider whether the benefits indicated by satisfaction of the criteria are outweighed by the drawbacks indicated by the criteria which are not satisfied.

The choice of a change-management strategy will rarely be clear-cut. Although there is a natural tendency amongst project and contract managers to opt for the strategy of change reduction, this may not be to the ultimate benefit of all the stakeholders involved in the creation and use of the system. A strategy of encouraging change to improve the final system will usually be more beneficial in terms of system quality, functionality, and user satisfaction. We recognise that despite the best efforts of methodologists and practitioners, it is rare that a set of requirements can be made complete and accurate before design begins, and that even attempts to identify change as early as possible in the lifecycle will not be infallible.

We might at this point observe that a typical system lifecycle begins with a strategy to reduce change by attempting to define a complete set of requirements, combined with a strategy of identifying change early by applying techniques to confirm the accuracy of this set of requirements. It then at least partially deploys a strategy aimed at facilitating the incorporation of change in order to minimise the problems of requirements changes which emerge as work proceeds, and finally, as the delivery date nears, resorts to a change reduction strategy of refusing all but the most essential of changes.

Most practitioners will recognise this scenario, but many variations are possible. In a highly innovative system, for example, it will be recognised that frequent change will almost certainly occur throughout the lifecycle, and that the dominant strategy should be one of facilitating the incorporation of change. Conversely, the supplier bidding a fixed price against a defined set of requirements will adopt a strategy of change reduction, since this is the most cost effective means of fulfilling the letter of the contract.

What we are saying here is that there are certain circumstances specific to a particular project which are in effect strategy drivers. The first of these, the stage reached in the lifecycle, strongly influences the strategy for
handling change from the project manager's point of view and may also affect it in that the source of change will migrate from the customer in the early requirements formation stage, to the supplier in the requirements engineering and design stages, and ultimately to the user in the operational stage. The degree of system innovation is another strategy driver, in that more change will have to be accommodated when a major new system is being developed than when the project is a major new release or merely updating an existing system. The third strategy driver recognised is the system environment. At one extreme is a closed system with a controlled environment where relatively little change should be necessary, whereas for an open system in a turbulent environment, change will be frequent and difficult to integrate.

Before the criteria can be applied one must therefore decide on the combination of strategies for dealing with change which will be most appropriate for the particular circumstances in which the method is to be deployed, and the relative importance of each of these strategies. It should be noted that no single method is expected to satisfy all criteria within a single strategy-specific set. The objective should be to select a combination of methods which complement each other in their ability to satisfy the criteria.

Having first applied a suitable combination of strategy criteria, the utility criteria should then be applied to validate how the method will perform in practice. We consider the utility criteria important in the context of change because we have observed how methods introduced to manage change have sometimes created additional problems in the change process which could have been predicted by application of these criteria. These criteria may be considered to be more applicable to tools and methods rather than to processes, but, as even a process can be evaluated against criteria such as 'reliable' or 'efficient', we maintain that the criteria will always be relevant in some degree to whatever type of 'method' is being evaluated.

The context criteria may be regarded as a 'reality test' for the successful adoption of a method. An experimental project conducted within the research department of an organisation may be able to adopt methods without reference to the normal organisational context, but when placed in the context of a typical project undertaken by the mainstream of the organisation, greater constraint may be evident in selecting methods for handling change. Despite this, we do not regard these criteria as representing immutable constraints, but as a means of assessing what other changes must be made in order to successfully adopt the method. It is for the practitioner to decide whether implementing the context changes indicated is worth the benefits offered by the method.

Finally, the basic criteria should be applied. They represent important underlying properties abstracted from our study of processes, methods and tools used in managing change, and, as for the strategy-specific criteria, it is not expected that any one method will satisfy all of these, but that the combination of methods selected should complement each other in their ability to satisfy the basic criteria. Indeed, it may be that if the combination of methods selected overfulfills some of the basic criteria then this might indicate an unbalanced choice of methods.

7. Conclusions

We have attempted to identify what attributes are needed by requirements and design methods, processes, techniques and tools in order to minimise the adverse impact of change. Three strategies for handling change have been recognised: identifying change early in the lifecycle, facilitating its incorporation, and reducing or
suppressing it. We have also acknowledged the importance of utility and context factors and the basic properties that are desirable of methods for their primary requirements or design function as well as for handling change.

We have presented a schematic set of criteria and have proposed guidelines which may be adopted for informed use of the criteria as a checklist against which to assess the suitability of interlinked methods, subprocesses, techniques and tools for the management of change. The final set of criteria offers a means of assessing the completeness of such a process.

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References
### Table 1 Strategy-specific criteria

#### Criteria for reducing change

Completeness of Requirements Elicitation
- requirement classes
  - functional
  - non-functional
  - organisational
- methods
  - scenarios
  - interviews
  - ethnography

Accuracy and Precision of Requirements
- stepwise refinement
- formal proofs

Unambiguous Representation
- to users
  - models
  - prototypes
- to designers
  - formal methods

Tight Control
- contracts
  - project management

#### Criteria for identifying change early

Option Generation
- brainstorming
- modelling
- prototyping

Exploration of Requirement and Design Uncertainty
- sensitivity analysis

Prediction
- prototyping
- simulation
- design animation

Early Evaluation
- walk throughs
  - consistency checks
  - feedback to/from:
    - users
    - customers
collaborators
suppliers
Concurrency - interdisciplinary teams
- early integration

Criteria for facilitating the incorporation of change
Representation - partial (areas of uncertainty)
- indicating potential for change
- variants/versions
Representation Transfer
- clarity
- interfacing to other methods
- translation to other methods
- linkage to other parts of the design
Explicit Design Rationale
- traceability
- recording decision history
- self-documenting
Impact Analysis
- prediction of consequences
Risk Management
- risk identification
- risk analysis
- risk prioritisation
- risk management planning
- risk resolution
- risk monitoring
Design Flexibility
- modularity
- object orientation
- re-configuration potential
- user configuration
### Table 2. Utility criteria

| Usability       | - ease of learning  
|                 | - ease of use       
|                 | - efficiency        
|                 | - user satisfaction  
|                 | - safety            
| Dependability   | - reliable          
| Timeliness      | - can deliver to timescale  
|                 | - available when needed  
|                 | - suitable for stage reached in lifecycle  
| Compatibility   | - with standards  
|                 | - with other tools and methods  
| Scaleability    | - appropriate for size of project  

### Table 3. Context criteria

| Inter-organisational | - culture  
|                      | - communication  
|                      | - contracts  
|                      | - regulation  
|                      | - standards  
| Organisational       | - culture matching  
|                      | inertia acceptability  
|                      | structure functional management skill base  
|                      | objectives goals policy  
|                      | integrity commercial confidentiality security  
|                      | timescales workflow business cycles  

| Project Resources   | - financial  
|                     | - human  
|                     | - skill base  
|                     | - physical  

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