Benefits of Traceability in Software Development

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For starters I'll have "Who?", "What?", "When?", "Where?" and the "Wither?", "Whence?" and "Wherefore?" to follow, and one big side order of "Why?"

(Zpaphod Beeblebrox in the Hitch-Hikers Guide to the Galaxy, by Douglas Adams, writer, 1952-2001)

Acknowledgements

I would like to thank, first and foremost, my PhD supervisor Dr Steve Riddle for his patience, guidance and his abundant supply of red ink. Secondly, I would like to thank my family and colleagues, in particular John Fitzgerald, Cristina Gacek and Jim Armstrong, for their help and encouragement in those dark days of writing-up. Thirdly, I would like to thank Dr Tom Brookes (BAE SYSTEMS) for his guidance in the practical aspects of Traceability. Finally, I would like to thank Professor Tom Anderson and the BAE SYSTEMS customers of the Dependable Computing Systems Centre for affording me the opportunity to undertake this thesis.

Publications

The following papers have been published from this work:

Presented at the 1st International Workshop on Traceability in Emerging Forms of Software Engineering in conjunction with the 17th IEEE International Conference on Automated Software Engineering September 28th, 2002 Edinburgh, U.K.

Position Paper: Enabling Traceability

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Abstract

Research into traceability at the University of Newcastle upon Tyne has concentrated on a framework supporting all aspects of the lifecycle, as a vehicle for recording, analysing and tracing development and assessment artefacts. This framework is focussed on the recording of design rationale, over and above the standard inter-relationships between product artefacts, and has been developed in an aerospace systems engineering context. Despite technological advances in terms of databases, internet and processing power, many aspects of the requirements traceability problem are still current. We look at the reasons for this and suggest some research areas to address some of these aspects.

Presented at the 13th IEEE International Requirements Engineering Conference, La Sorbonne, France, August 29-September 2, 2005.

Overcoming the Traceability Benefit Problem

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Abstract

To modify complex computer-based systems requires a detailed understanding of their functionality. Requirements Traceability can help the engineer to gain that understanding, but several surveys have observed that traceability information is poorly recorded. We argue that the cause is the lack of direct perceived benefit to the main development process. As a consequence traceability information will be

incomplete, inaccurate and out-of-date. We propose a method of recording traceability information, a Traceable Development Contract (TDC), as a means of reducing this problem by tackling the issue of an upstream functional development team imposing changes on a downstream development team. The contract makes the recording of traceability information beneficial to both development teams.

Presented at the 14th IEEE International Requirements Engineering Conference, Minneapolis/St. Paul, USA, September 11-15, 2006 and at the BAE SYSTEMS SPIRE Conference, Hinckley, Leicestershire, UK, October 23-26, 2006.

Tailoring Traceability Information to Business Needs

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Abstract

Several surveys over the past 20 years have observed that traceability information is often poorly recorded. In previous work, we have argued that this is a result of many requirements traceability systems failing to provide any direct benefit to the development process. In this paper, we describe an application of traceability by a company, with a resulting increase in profitability as well as other benefits for the development engineer, project management and customer.

Abstract

For an engineer to be able to modify successfully a complex computer-based system, he will need to understand the system's functionality. Traceability can help the engineer to gain that understanding, but several surveys have observed that traceability information is poorly recorded. This thesis argues, based on a survey of nine aerospace projects, that one of the main causes of poor recording is that Traceability does not directly benefit the development process. The recording of traceability information is best performed by the engineers directly involved in the development process, yet it is precisely these engineers who seem to obtain no direct benefit in performing this task. This can be summarised as the *Traceability Benefit Problem*. To overcome this problem the recording of traceability data must provide immediate, tangible benefits to the engineers involved in the current development process.

A related problem that occurs in large multi-team projects that follow development processes based on predictive models (such as Waterfall or V-Model) is the changing of interface documentation without adequate negotiation (referred to as *Throwing the Problem over the Wall*). This thesis describes, in detail, how a small automotive sensor project addressed these problems by developing a Requirements Traceability system that enabled the reuse of software and provided a basis for the negotiation of changes with their customer. Analysis of the lessons learnt from the automotive sensor and aerospace projects lead to the definition of the Traceable Development Contract.

The contribution of this thesis is the description and discussion of the Traceable Development Contract, a method of coordinating the interaction of related development teams in development process that is based on a predictive development model. The Traceable Development Contract is proposed as a means of controlling the upstream team bias with respect to the imposition of changes, by employing traceability to provide a basis for the negotiation of change. By employing traceability in this way, it becomes beneficial to the development engineers and therefore overcomes the Traceability Benefit Problem.

Finally, the thesis considers how the Traceable Development Contract traceability information can be exploited further to provide solution maturity and design metrics.

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Chapter 1 Introduction

1.1 Introduction

For an engineer to be able to modify successfully a complex computer-based system, he will need to understand the system's functionality. One way to gain this understanding is to review the development artefacts looking for common threads of reasoning. Traceability[1] defined as, "a property of a system description technique that allows changes in one of the three system descriptions - requirements, specifications, implementation to be traced to the corresponding portions of the other descriptions" [Greenspan and McGowan 1978] can help the engineer to determine these threads.

Development standards such as ISO 9003 [ISO 2007] and TickIT [TickIT 2000] require that a project shall be able to demonstrate Requirements Traceability.

[1] The term "Traceability" is often prefixed with "Requirements" to demonstrate the source of the trace relationships. The general term "Traceability" refers to the recording of all trace relationships.

These standards are unclear on precisely what information is required to be recorded and to what use it should be put. Researchers have addressed this problem by determining what development artefact properties and relationships are required to be recorded to improve the efficiency of the development process and the quality of the product. This research has mainly concentrated on the evolution of requirements and as a result there are a number of requirements management tools [INCOSE 2007] such as DOORS [DOORS 2003], which allow the recording of traceability relationships between requirements. At present, traceability is mainly applied to the requirements development phase and traceability beyond that phase is seldom achieved in an industrial environment, as demonstrated by the Traceability Practices Survey (Chapter 3).

1.2 Thesis Hypothesis

Given that Traceability is a desired or mandatory technique and there are proven information structures and tools that support these structures, it seems odd that the take-up and execution within industry is poor [Ramesh et al. 1993] [Gotel and Finkelstein 1994] [Arkley 2002].

We argue that the lack of direct benefits to the main development process from Traceability, which we define as the *Traceability Benefit Problem*, is a major cause of the above situation. We state that the recording of traceability information is best performed by the engineers who are directly involved in the development process and it is these engineers who seem to obtain no benefit in performing this task. This lack of benefits causes the development engineers and their management to assign a very low priority to the recording of traceability information, often resulting in data that is incomplete, inaccurate and out of date.

1.3 Thesis Contribution

The contribution of this thesis is the proposal of a Traceable Development Contract, which consists of a process and information model for coordinating the interaction of related development teams in development process that is based on a predictive development model. The Traceable Development Contract is a means of controlling the upstream team bias with respect to the imposition of changes, by employing traceability to provide a basis for the negotiation of change. By employing traceability in this way, it becomes beneficial to the development engineers and therefore overcomes the Traceability Benefit Problem.

1.4 Background to Proposed Solution

A traditional view of the poor uptake and execution of Traceability is that it is a technical problem, which can be improved by the greater integration of development tools or by the use of search engines [Herzog 2000] [Antoniol et al. 2002] [Marcus and Maletic 2003] [Huffman et al. 2006]

This thesis questions the technical based solution by considering the factors involved in determining a trace between two artefacts belonging to different development phases. An argument is made that only the engineers directly involved in the development transformation, such as developing a design from the requirements, can consistently record the correct relationships between development artefacts. This argument is employed to validate the poor results presently obtained by offline traceability recording teams (described in Chapter 3) and search engines (described in Chapter 4).

From the results of a Traceability Practice Survey (Chapter 3), an argument is developed that states engineers will only record this information consistently if it is beneficial to their immediate development task: we refer to this as the Traceability Benefit Problem.

One of the projects in the Traceability Practice Survey, the Automotive Sensor project (Chapter 5), demonstrated how the Traceability Benefit Problem could be overcome by the development of a traceability system that was beneficial to their development process. The resulting traceability system enabled the reuse of software and provided a basis for the negotiation of customer changes. The automotive sensor project was unique among the surveyed projects as it was developed by a small multidisciplinary team: the rest of the surveyed projects were large multi-team projects that followed development processes based on predictive development models.

The Traceability Practice survey (Chapter 3) highlighted a related issue that occurs in large multi-team projects, where an upstream development team imposes changes on a downstream team without any negotiation. This has been observed by other researchers [Al-Rawas and Easterbrook 1996] [Curtis et al. 1988] [Christie et al.1996] and is often referred to as *"Throwing the problem over the wall"*. Development processes based on predictive development models have the problem of establishing a suitable development phase baseline to allow development to advance. Changes to baselines will always occur during development.

Development models say little with respect to how teams involved in different development phases should interact and negotiate change. Boehm tackled this issue in his Theory-W of software management [Boehm and Ross 1989]. In this theory, he states that negotiations require structure and objective information about the proposed change. The determination of the impact of a change to a development baseline is such an item of objective information. To determine the impact of a change requires the recording of traceability relationships between the baseline and the next development phase. This is how the Automotive Sensor team beneficially employed traceability to negotiate change with their customer. A similar use of traceability in the context of a structured interaction would make the recording of traceability information beneficial to both development phases and therefore it would overcome the Traceability Benefit Problem for multi-team development processes.

1.5 Proposed Solution

The Traceable Development Contract (TDC) is proposed as means of providing structure and objective information to change negotiations. The TDC formalises the interaction of two development teams by defining their behaviour with respect to the state of their common development artefacts. Traceability is employed as a means of assessing the impact of a change to the common development artefacts and providing a basis for the negotiation of the change. The TDC affords the engineers in the downstream development phase an element of control over their development environment by controlling the imposition of changes by the upstream development team. By keeping the definition of the TDC generic, for example the interaction between an upstream problem defining phase (e.g. software requirement definition) and a downstream development phase (e.g. software design), the contract can be applied across a number of development interfaces and therefore achieving traceability beyond the requirements development phase. The TDC consists of three parts:

- <u>Problem artefacts</u> (documentation, diagrams, models etc) that describe the problem domain.
- <u>Traceability data structures</u> that record how the problem information artefacts are related to a proposed solution. For example, traceability structures that record the relationship between a software design and a requirement set.
- <u>A protocol</u> that defines the behaviour of each development phase with respect to changes to the problem information artefacts or solution.

1.6 Thesis Structure

The thesis is divided into ten chapters.

Chapter 1 Introduction: This chapter lays the foundations for the thesis by describing the technical problem, thesis hypothesis, thesis contribution, proposed solution and finally the structure of the thesis.

Chapter 2 Traceability: This chapter describes the origins, development of Traceability definitions and current implementation techniques. The aim of this chapter is to provide a foundation for the following chapters by clarifying terms and definitions.

Chapter 3 Traceability Practice Survey: This chapter describes motivation and the method of a survey of traceability practices performed by a number of BAE SYSTEMS projects. The results of the survey are compared and contrasted with two widely cited studies on Requirements Traceability practice performed by Gotel [Gotel 1995] and Ramesh [Ramesh and Jarke 1999b; Ramesh et al. 1995].

Chapter 4 Traceability Benefit Problem: This chapter builds upon Chapter 3 by analysing the results of the Traceability Practice Survey in detail. From this analysis, an argument is developed that states that one of the major causes of the observed Requirements Traceability practice issues is the lack of benefit that it provides to the current development process. We define this as the Requirements Traceability Benefit Problem.

Chapter 5 Automotive Sensor Case Study: This chapter describes in detail how Electronics and Integrated Solutions (E&IS), one of the BAE SYSTEMS surveyed projects, developed a Traceability system which addresses Traceability Benefit Problem. The chapter describes and illustrates with project data the development process and traceability system. Finally, the chapter describes the benefits the traceability system provides to the development engineer, the project management and their customer.

Chapter 6 Negotiating Change: Chapter 5 described how the automotive sensor project employed a traceability system to help them negotiate changes to their baseline requirements. The Traceability Practice Survey (Chapter 3) highlighted the problem of establishing and maintaining development phase baselines. During the survey, a number of engineers raised issues relating to the fact that the re-issuing of interface documentation without any consultation or negotiation (referred to as *Throwing Problem over the Wall*). This chapter examines the issue of change negotiation by considering what software development models have to say on the subject. Finally, the BAE SYSTEMS Common Engineering Process Model (CEP) is reviewed as many BAE SYSTEMS development processes are based on this or a similar development model. The CEP is reviewed with respect to change negotiation and the results are related to the observations made during the Traceability Practice Survey.

Chapter 7 Traceable Development Contract: Chapter 6 highlighted the weaknesses in predictive development models with respect to establishing development phase baselines and the inherent bias these models have towards upstream development phases making changes to the baseline. Chapter 5 described how the automotive sensor project employed a traceability system to help them negotiate customer changes to their baseline requirements. This chapter combines these themes and introduces the Traceable Development Contract (TDC). The TDC is proposed as a means of controlling the upstream team bias with respect to the imposition of changes, by employing traceability to provide a basis for the negotiation of change. By employing traceability in this way, it becomes beneficial to the development engineers and therefore overcomes the Traceability Benefit Problem.

Chapter 8 TDC Traceability Data Structures: This chapter examines the data structures required to achieve the aims of the TDC. This chapter describes how design of the structures has been influenced by previous traceability structures and the Traceability Practice Survey. The chapter concludes by examining how the TDC traceability data structures can be exploited further to provide solution maturity and design metrics.

Chapter 9 An Illustration of the TDC: Chapter 7 outlined the TDC protocol and Chapter 8 described the data structures required to support the contract. This chapter builds upon this work by describing how a contract may work in practice. To illustrate the TDC, and the complexity of the aerospace industry, this chapter will consider the development of the Mission Planning System software for a hypothetical Jet trainer. The illustration is not a proof or a validation of the TDC, it is presented here as a means of exemplifying the ideas presented the previous chapters.

Chapter 10 Lessons Learnt and Future Work: This chapter summarises the problems and achievements of this work. The chapter describes the history of the development of the ideas in this thesis and finally, discusses how the work presented can be extended further.

Chapter 2 Traceability

2.1 Introduction

This chapter investigates the origins of Traceability and the evolution of the literature definitions. The chapter examines the need for Traceability in the development process and summarises the data models and tools that have been developed to achieve Traceability.

2.2 Origins of Traceability

The term Requirements Traceability appears to have been coined in the 1950s by the US military during the development of electro-mechanical systems [Alford 1994]. During this period, Traceability broadly referred to the ability to demonstrate that a system satisfied a set of requirements. As software engineering developed from its electro-mechanical parentage, Requirements Traceability was adopted and applied to the development of software. By the mid 1970s it became apparent that software development required new techniques: this is commonly referred to as the Software Crisis [Dijkstra 1972]. At this time Alford [Alford

1977] identified a need to improve traceability between system modelling and system requirements and between requirements and the originating specification documents. The 1970s also saw the introduction of the first requirements tracing tools [Pierce 1978].

In the 1980s Boehm illustrated his Spiral model [Boehm 1986] by describing the development of a Software Productivity System (SPS) which included a Requirements Traceability Tool (RTT). The 1990s saw an upsurge in interest in requirements traceability. This upsurge appeared to have two causes. The first cause was the availability of commercial relational database systems for common PC platforms, which lead to the development of commercial requirements managements systems such as DOORS (Dynamic Object–Orientated Requirements System[2])[DOORS 2007] and RTM (Requirements and Traceability Management system[3])[RTM 2007]. This instilled interest in both the academic and industrial communities on how these new tools could be best exploited.

The second cause appears to have been a related upsurge in interest in Requirements Engineering [Gotel 1995]. There are many definitions of Requirements Engineering though one of the most commonly cited is Definition 2-1. Though, the application of analysis methods to requirements dates back to the 1970s [IEEE 1977], Requirements Engineering became established in the early 1990s (the first International Symposium on Requirements Engineering was held in 1993) when new requirements analysis methods were being developed.

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[2] DOORS was originally developed by Quality Systems and Software (QSS) in the early 1990s and is currently being developed by Telelogic

[3] RTM was originally developed by Marconi Systems Technology in the early 1990s and is currently being developed by Serena.

Definition 2-1

Requirements Engineering

"Requirements engineering is the branch of software engineering concerned with the real-world goals for functions of and constraints on software systems. It is also concerned with the relationship of these factors to precise specifications of software behaviour, and to their evolution over time and across software families." [Zave 1997]

The 1990s saw significant advances in Requirements Engineering research such as the development of techniques for eliciting and analysing stakeholders' goals, modelling scenarios that characterise different contexts of use, the use of ethnographic techniques for studying organisations and work settings, and the use of formal methods for analysing safety and security requirements.

As Requirements Traceability is an aspect of Requirements Engineering it also saw an increase in research effort. This research effort was initially directed at the problem of requirement elicitation. This had been an ongoing problem in systems development, as demonstrated by an early empirical study by Bell and Thayer [Bell and Thayer 1976]. They observed that inadequate, inconsistent, incomplete or ambiguous requirements are common and have an impact on the quality of the resulting software. They stated that "*The requirements for a system, in enough detail for its development, do not arise naturally. Instead, they need to be engineered and have continuing review and revision*" [Bell and Thayer 1976]. Boehm highlighted the cost of not getting the system requirements correct, stating that the cost of correcting requirement related error increased rapidly as development proceeded [Boehm 1981]. Requirements Traceability researchers during this period tackled issues related to the recording and analysis of requirement development rationale [Nuseibeh et al. 1994] [Riddle and Saeed 1998] [Riddle and Saeed 1999a] and the recording of contributions by development actors [Gotel 1995].

The new millennium saw the introduction of a wide range of Extensible Mark-up Language (XML) [XML 2007] tools and this caused a change in the direction of Requirements Traceability research. Researchers started explored how these tools could be employed to record traceability relationships between diverse sources. Two features of XML appeared to have created the most interest, the ability to record metadata about an artefact in a known format, and use of the bidirectional Xlinks [Xlink 2007]. A number of researchers [Alves-Floss et al. 2002][Anderson et al 2002][Collard et al.2002][Zisman et al 2003] have proposed ways of employing these XML technologies to create traceability information frameworks.

2.3 Literature Definitions

There have been a number of Traceability definitions. One of the earliest definitions (Definition 2-2) came from Greenspan & McGowan [Greenspan and McGowan 1978].

Definition 2-2

Traceability is a property of a system description technique that allows changes in one of the three system descriptions - requirements, specifications, implementation- to be traced to the corresponding portions of the other descriptions" [Greenspan and McGowan 1978]

This broad definition of traceability persisted until Davis introduced the idea of direction to traceability relationships (Definition 2-3).

Definition 2-3

"Traceability can be defined as the ability to describe and follow the life of an artefact, in both a forward and backward direction, i.e. from its origin to development and vice versa" [Davis 1990]

The introduction of a notion of direction to traceability relationships influenced a number of researchers. One of the most notable contributions was from Gotel who employed this idea to tackle the problem of pre-requirements elicitation. Gotel expanded upon Davis's earlier definition to establish a definition for Pre and Post Requirements Traceability (Definition 2-4).

Definition 2-4

"Pre-requirements traceability (pre-RT) refers to the ability to describe and follow those aspects of a requirement's life prior to its inclusion in the requirements specification in both a forwards and backwards direction (i.e., requirements production and refinement).

Post-requirements traceability (post-RT) refers to the ability to describe and follow those aspects of a requirement's life that result from its inclusion in the requirements specification in both a forwards and backwards direction (i.e., requirements deployment and use)". [Gotel 1995]

A number of researchers [Bersoff and Davis 1991] [Gotel 1995] [Mason 1999] extended the notion of direction to establish a distinction between artefact version (or horizontal) traceability and inter-development phase artefact (or vertical traceability) as shown in Figure 2.1. Horizontal traceability occurs between iterations of the same artefact, this is commonly known as version control. Vertical traceability occurs between artefacts in different development phases, for example relationships between a requirement specification and a design artefact. Mason [Mason 1999] took this two dimensional view and argued the presence of a third dimension (Figure 2-2) which captures the traceability relationships for a given revision or release of a system.

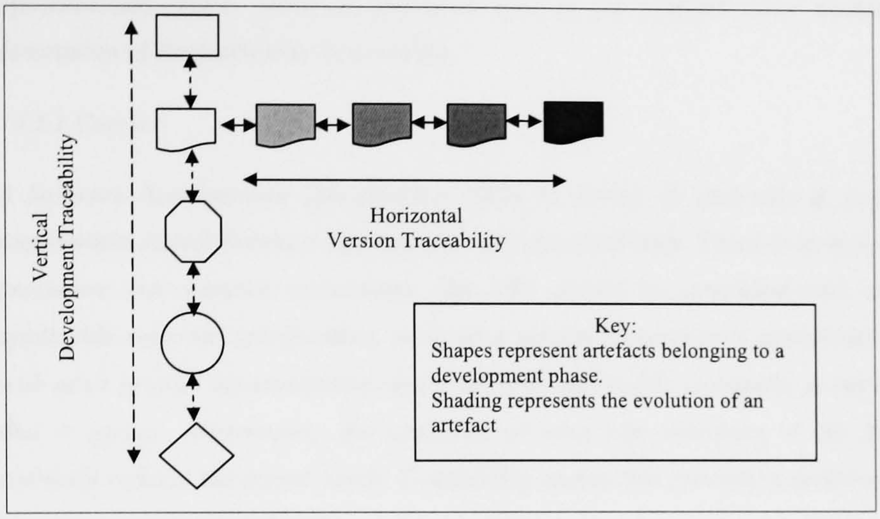

Vertical
Development Traceability
Horizontal
Version Traceability
Key:
Shapes represent artefacts belonging to a development phase.
Shading represents the evolution of an artefact

Figure 2-1 Vertical and Horizontal Traceability [Mason 1999]

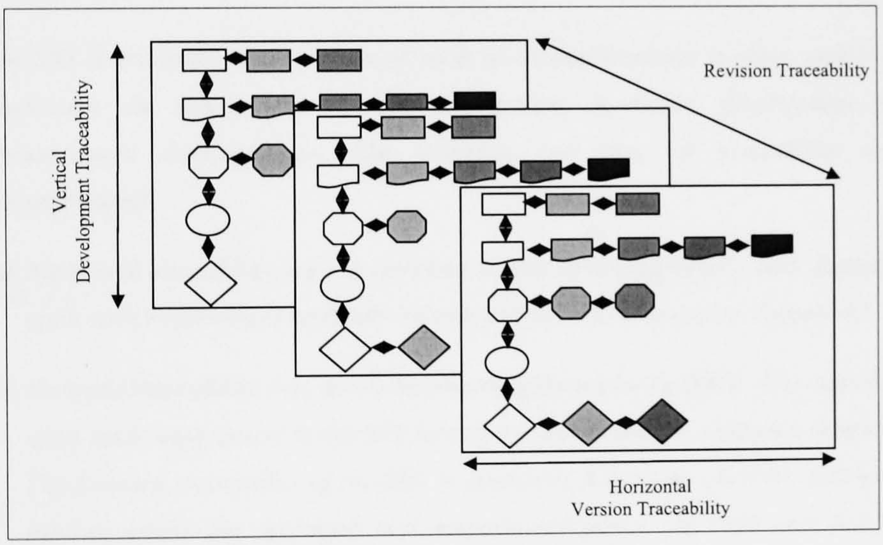


Figure 2-2 Vertical, Horizontal and Revision Traceability [Mason 1999]

The previous definitions are from the academic community. The following text which is taken from IEEE Recommended Practice for Software Requirements

Specifications [IEEE 1998] is presented here as an example of a working description of Requirements Traceability.

"4.3.1 Correct

A Software Requirements Specification (SRS) is correct if, and only if, every requirement stated therein is one that the software shall meet. There is no tool or procedure that ensures correctness. The SRS should be compared with any applicable superior specification, such as a system requirements specification, with other project documentation, and with other applicable standards, to ensure that it agrees. Alternatively the customer or user can determine if the SRS correctly reflects the actual needs. Traceability makes this procedure easier and less prone to error (see 4.3.8)...

4.3.8 Traceable

An SRS is traceable if the origin of each of its requirements is clear and if it facilitates the referencing of each requirement in future development or enhancement documentation. The following two types of traceability are recommended:

a) Backward traceability (i.e., to previous stages of development). This depends upon each requirement explicitly referencing its source in earlier documents.

b) Forward traceability (i.e., to all documents spawned by the SRS). This depends upon each requirement in the SRS having a unique name or reference number. The forward traceability of the SRS is especially important when the software product enters the operation and maintenance phase. As code and design documents are modified, it is essential to be able to ascertain the complete set of requirements that may be affected by those modifications." [IEEE 1998]

This definition tries to answer a criticism, which has been aimed at the previous definitions, that they all fail to state why requirements traceability should be performed. This highlights a problem faced by many development managers who are required to implement Requirements Traceability due to a need to be compliant to a development standard. Many Requirements Traceability definitions and development standards are unclear why it should be performed and what benefits will be obtained by performing traceability. Without this information, it is difficult for these managers to determine the correct level of effort to be assigned to this task.

2.4 The Need for Traceability

The perceived need for Traceability is dependent on each stakeholder's view of the development process.

2.4.1 Customer

For the Customer, Requirements Traceability is needed as a means of showing that the product satisfies the requirements. This is achieved by demonstrating the traceability relationships between acceptance tests and the requirements and also design and the requirements.

2.4.2 Project Manager

For the project manager, Traceability provides a range of project status information. The rate of establishment of traceability relationships provides a means of assessing progress. The distribution of traceability relationships can highlight areas of high dependency or development bottlenecks. Traceability provides the project manager a means of assessing the impact of a change, allowing him to allocate the correct level of resource to the change.

2.4.3 Requirements Analyst

For the requirements analyst, Requirements Traceability provides a means of recording the contribution of each stakeholder during requirements elicitation. It also provides a means to check the correctness and consistency of the developing requirements.

2.4.4 Designer

For the designer, Traceability provides a means of demonstrating that the design satisfies the requirements and how it will be verified. The traceability relationship between the design and the requirements allows the designer to determine the impact of any changes to requirements on the design or the impact of design changes on the ability to satisfy the requirements. Traceability also provides the designer a means of recording design rationales and design alternatives, which can be employed in a design justification.

2.4.5 Maintainer

For the maintainer, Traceability provides a means of gaining an understanding of the product. By traversing the traceability relationships the maintainer is able to determine the impact of a change. The traceability information also provides the maintainer a means of determining the testing required to validate the systems after a change.

2.5 Traceability Link Semantics

Each of the above development roles requires different set of link semantics to be recorded. The following is a summary of the link semantics, which have appeared in the literature.

- Requirements related links.
    - Linking a requirement to its source documents.
    - Linking a requirement to the personal details of the stakeholders who developed the requirement.
    - Linking a requirement to its change history (configuration and control)
    - Linking a requirement to a justification, that gives the reasons for the requirement

    - Linking a requirement to subsystem requirements (requirements decomposition).
    - Linking a requirement to design artefact(s).
    - Linking a requirement to a validation test(s).
- Design artefacts related links.
    - Linking a deign artefact to the personal details of the stakeholders who developed the artefact.
    - Linking a design artefact to requirements.
    - Linking a design artefact to subsystem design (design decomposition).
    - Linking a design artefact to another artefact that describes the problem domain from a different viewpoint.
    - Linking a design artefact to a design rationale.
    - Linking a design artefact to its change history (configuration and control).
    - Linking a design artefact to a validation test(s).
- Code Module related links.
    - Linking a code module to the personal details of the stakeholders who wrote the code.
    - Linking a code module to design artefacts.
    - Linking a code module artefact to subsystem (code decomposition).
    - Linking a code module to an implementation rationale.
    - Linking a code module to its change history (configuration and control).
    - Linking a code module to a validation test(s).

This list is not definitive or exhaustive. It can be seen that there are similar traceability relationships in each development phase (requirements, design and code), such as the recoding of the stakeholder relationships. Given these common traceability relationships, a number of researchers have proposed traceability development models that describe how traceability relationships are recorded and exploited during the development of a system.

2.5.1 Traceability Models

One of the first of these models was the evolution support environment (ESE) system [Ramamoorthy et al.1990]. The ESE model considers a system to be composed of a hierarchical structure of generic objects. These objects are connected by three types of traceability link: hierarchical links between objects at different levels of the hierarchy, historical links between versions of one object and development links between different objects at different stages of development. The ESE traceability model was implemented using the Ingres relational database in conjunction with the UNIX SCCS version control system.

Gotel [Gotel 1995] considered problem of pre-requirements traceability, that is recording the relationships with respect to contributions made to an evolving requirement. In her thesis, Gotel addressed this problem by proposing a set of Contribution Structures. The evolution of a requirement is represented by a hierarchy of artefacts connected by either change relationships or reference relationships. Contributors are related to requirement artefacts by contribution relations that are defined by their role in the development process.

The ESPRIT NATURE project demonstrated a prototype Requirements Engineering environment called PRO-ART [Pohl 1996]. The PRO-ART tool allows the tracing of the development or evolution of a requirement in three dimensions.

Representation Dimension: This ranges from informal to formal. Moving along this dimension is technical problem. The dimension records the representation of a requirement from informal notes, structured text and finally to formal specification.

Agreement Dimension: This ranges from partial to complete and is orthogonal to the representation dimension. Moving along this dimension is a social process. This is represented by issues about which decision must be made. An issue may be related to an object in the specification dimension. About each issue, one or more positions are stored and for each position a rationale is recorded.

Specification Dimension: This dimension ranges from opaque to complete understanding of the requirement. Movement along this dimension represents the cognitive and psychological problems of the requirements engineering. This dimension is orthogonal to agreement and representation dimensions.

The DoD traceability model has evolved from the work of Ramesh and Edwards [Ramesh et al. 1995] at the Naval Postgraduate School in Monterey. Ramesh and Edwards developed a number of interrelated traceability models by observing current development practices and from interviews with engineers working on large DoD software development contracts. Their models consisted of a requirements management model, a design to implementation model, decision rationale model and compliance verification model. Each of these models contains a set of permissible information types and a set of permissible relationships. For example, Figure 2-3 describes the requirements management model.

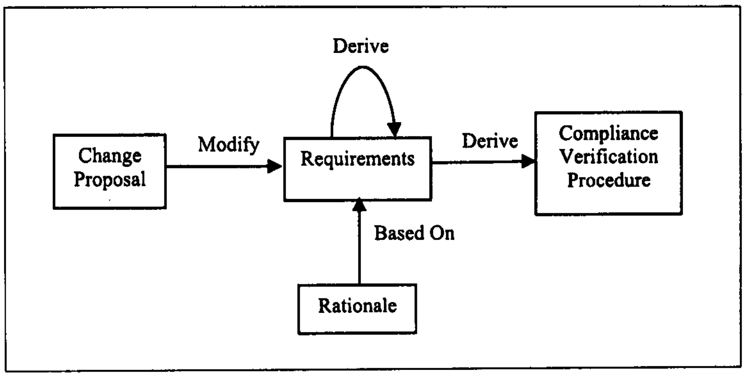


Figure 2-3 DoD Requirements Management Model

These models were further extended and refined by Ramesh and Jarke [Ramesh and Jarke 1999a] (CREWS project). The models were implemented using ConceptBase [ConceptBase 2007] and the SLATE engineering development tool (now obsolete). Ramesh claimed that these models were successful though he restated older problems relating to tool implementation and development processes which he raised in 1995 with Edwards [Ramesh, Stubbs, Powers and Edwards 1995].

Another example of a traceability data model is the Meta-Modelling Approach to Traceability for Avionics (MATra) [Mason 1999]. MATra is an object–based approach to tracing artefacts for the development and assessment of aviation electronic (avionics) systems. It is based on a set of interconnected "traceability structures" specified using the class diagram view from the UML, with integrity constraints over these structures expressed in the Object Constraint Language (OCL).

Though not a traceability data model, the AP233 application protocol data model [Herzog 2000], is designed primarily to support design data exchange between software engineering tools, and provides some design traceability capabilities. This data model was developed to allow systems engineering development tools to share data.

However, there is still no clear agreement on a common traceability model as there are an unlimited number of traceability relations which can be recorded and as Wieringa [Wieringa 1995] stated: "the ultimate traceability tool is the world". What these models have demonstrated, in particular Contribution Structures and the DoD reference model, is how traceability can be applied to the development process to answer relevant development needs. A successful strategy for developing a traceability model, as demonstrated by the success of Gotel's and Ramesh's traceability models, is to start with a very simple model and to expand on this as the organisation gains an understanding of its rigour and usefulness.

2.6 Traceability Representation Techniques

Wieringa [Wieringa 1995] categorised the methods of representing a traceability relationship as matrices, entity relational models and cross referencing.

2.6.1 Matrices

A matrix is the simplest and the most common way representing a traceability relationship. The horizontal and vertical dimensions represent the artefacts that are to be linked. A mark at an intersection indicates a traceability link. All the links have the same semantics.

2.6.2 Entity Relationship (E/R) Model

E/R modelling is one of the best known semantic modelling approaches. It can be employed to describe the traceability links between entities. This technique has an advantage over the traceability matrix, in that links with higher arity than 2 (the maximum for a traceability matrix) can be represented. E/R Models can also be represented by relational database management systems (RDBMS) and this allows the ad hoc queries and reports to be made on the link data. Many of the commercial Requirements Traceability tools, such as DOORS [DOORS 2007] and RTM [RTM 2007], employ E/R modelling and relational database management systems to represent traceability relationships.

2.6.3 Cross-referencing

Cross-referencing is arguably the oldest traceability technique yet it has been given a new life with introduction of mark-up languages such as HTML and XML. In Cross-referencing the semantics of the link is contained in the text surrounding the reference. The link is represented by textual directions or in the case of HTML or XML by hypertext linking. Cross-referencing is simple to understand, though the traceability links are always binary and unidirectional. There are a number of examples of prototype project cross-referencing schemes, which employ tagging, numbering and indexing to implement traceability [Jackson 1991] [Zisman et al. 2003].

2.7 Traceability Tools

Tool support for Requirement Traceability can be divided into the following broad categories:

- Generic tools, such as spreadsheets, word processors, hypertext editors and database management systems (DBMS),
- Software Engineering Tools which provide traceability features.
- Requirements Traceability Tools, which provide dedicated requirements traceability support.

2.7.1 Generic Tools

The tools that fall into this category are word processors, spreadsheets editors, hypertext editors and database management systems (DBMS). These tools, with the exception of database management systems, mainly support cross-referencing traceability. Microsoft Excel is commonly employed to create traceability matrices.

Since Kaindl [Kaindl 1993] demonstrated how hypertext technology could be employed to record requirements traceability, HTML and XML editors have greatly increased in complexity and functionality though the basic referencing concepts that he described remain unchanged. The same can also be said of the work performed by Watkins and Neal [Watkins and Neal 1994], who described how common desktop tools could be employed to record requirements traceability. Since their work, Microsoft's dominance of the desktop market has resulted in a reduction of tools vendors but a greater integration of the Office products which overall has been beneficial to the execution of Requirements Traceability.

Database management systems (DBMS) can be employed to implement ER models that represent traceability relationships [Riddle and Saeed 1999b]. However, the direct use of a DBMS requires an understanding of relational database theory and SQL, which many practicing development engineers may not have. This has resulted in the development of dedicated Requirements Traceability tools, such as DOORS, which aim to hide the DBMS functionality from the engineer. The use of generic tools can be summarised as follows:

- They mainly support cross-referencing traceability techniques.
- They are readily available to all project members.
- They are generally easily understood (with the possible exception of DBMS) and require little training.
- They are flexible, though this may come with the incurred cost of developing bespoke scripts.
- They generally don't support any form of data analysis (with the possible exception of DBMS)

2.7.2 Software Engineering Tools

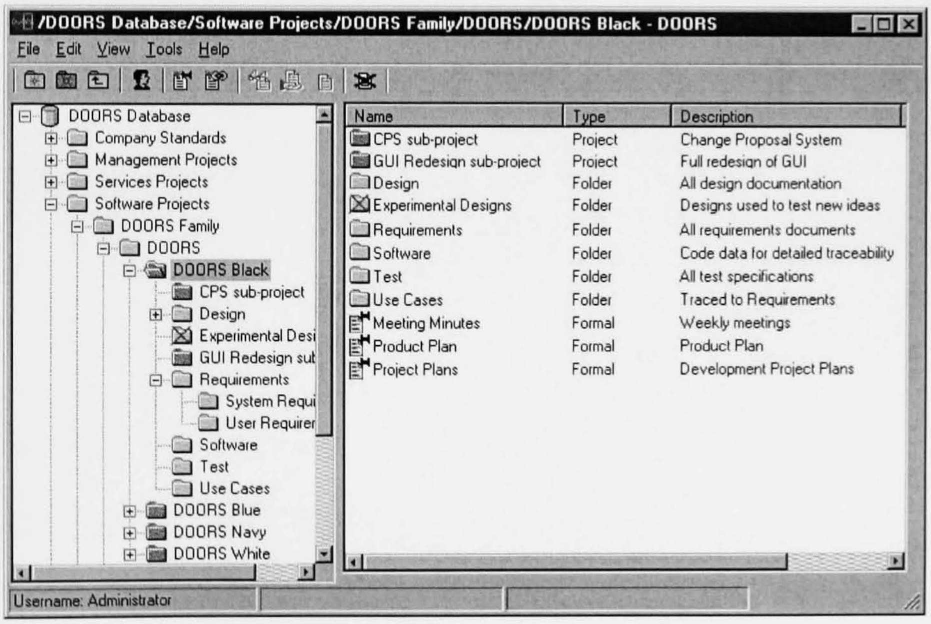
The prime aim of this group of tools is to provide a software development service and a traceability facility is just one of the many features provided. Most of the tools which fall into this class are Computer Aided Systems Engineering (CASE) tools, such as CRADLE [Cradle-5 2007]. This class of tools allow the development of objects to be traced, though this trace information is often limited to version control information. The use of software engineering tools can be summarised as follows:

- They sometimes only offer limited traceability data recording and analysis facilities. (Traceability is only one of the facilities offered by these tools).
- They do not easily allow traces to be made to information outside the tool's domain.
- They can be complex and require staff training to make use of the full potential of the traceability features.
- They are well suited to large projects as they allow distributed and controlled access to data.

2.7.3 Requirements Traceability Tools

This class of tools is mainly aimed at providing requirements traceability, though they can be employed to provide traceability throughout a project's lifetime. At present, there are two tools which dominate this area, DOORS (Dynamic Object Oriented Requirements System) [DOORS 2007], and RTM (Requirements and Traceability Management system) [RTM 2007]. A survey of traceability tool features has been performed by INCOSE [INCOSE 2007].

The market leader, DOORS has the ability to import a range of documents and to decompose them into a hierarchy of records based on the structure of the original document. Traceability between documents is achieved by link modules, which record the relationship between individual records. Documents are organised in folders akin to an operating system file system: Figure 2-4. The ease of use of the import functionality and the intuitive use of folders has been the key to the success of the DOORS tool.


/DOORS Database/Software Projects/DOORS Family/DOORS/DOORS Black - DOORS

File Edit View Tools Help

- DOORS Database
  - Company Standards
  - Management Projects
  - Services Projects
  - Software Projects
    - DOORS Family
      - DOORS
        - DOORS Black
          - CPS sub-project
          - Design
          - Experimental Desi
          - GUI Redesign sul
          - Requirements
            - System Requi
            - User Requirer
          - Software
          - Test
          - Use Cases
        - DOORS Blue
        - DOORS Navy
        - DOORS White

Name	Type	Description
CPS sub-project	Project	Change Proposal System
GUI Redesign sub-project	Project	Full redesign of GUI
Design	Folder	All design documentation
Experimental Designs	Folder	Designs used to test new ideas
Requirements	Folder	All requirements documents
Software	Folder	Code data for detailed traceability
Test	Folder	All test specifications
Use Cases	Folder	Traced to Requirements
Meeting Minutes	Formal	Weekly meetings
Product Plan	Formal	Product Plan
Project Plans	Formal	Development Project Plans

Username: Administrator

Figure 2-4 DOORS Folder Window

2.8 Summary

In summary, the practice of Traceability in software development has a long history and a number of data models and tools that have been developed to allow the engineer to make use of this valuable resource (as described in section 2.4). The next chapter considers the practical aspects of recording Traceability information by examining how a number of aerospace projects practice traceability.

Chapter 3 A Survey of Traceability Practices

3.1 Introduction

Management from a number of BAE SYSTEMS projects reported that there were issues in recording Traceability information in an industrial context. These issues were concerned with encouraging engineers to record and maintain Traceability information. The result of these concerns was a survey of how a number of BAE SYSTEMS projects practiced traceability.

This chapter describes the survey of traceability practices conducted on a number of BAE SYSTEMS projects. The motivation and the method of the survey are described here. The results of the survey are compared and contrasted with two widely cited studies on traceability practice performed by Gotel [Gotel 1995] and Ramesh [Ramesh et al. 1995].

3.2 Traceability Practice Survey Objectives

As stated in Chapter 2 there are many different Traceability implementation models and tools, each of which have their own particular strengths and weaknesses. However, BAE SYSTEMS project management were reporting issues with the recording and maintenance of Traceability information. With this in mind, a survey BAE SYSTEMS projects was undertaken, to understand the state of traceability practice. The objectives of this survey were to investigate how each of the projects currently performs Traceability and to determine what elements of "best practice" could be applied across the company.

3.3 Survey Design

Give the above objectives, the first stage in the development of a survey design is the determination of the unit of analysis [Babbie 1990]. The unit of analysis is what or whom is being studied. In the initial survey design, the units of analysis were a number of aerospace related projects, which were of a similar scale and complexity. After a trial run of an early version of the Preliminary Questionnaire it was found that this selection was too coarse and the units of analysis should be the engineers on the projects.

The next stage was to determine the type of survey to be conducted, cross-sectional or longitudinal. A cross-sectional study involves observing a subset of the population all at the same time, while a longitudinal study involves repeated observations of the same subset over long periods of time. The limited access to project engineers, due to their work commitments, favoured a cross-sectional survey. This decision was supported by the fact that the development methods and tools were unlikely to change during development and if repeated surveys were possible it is was unlikely that they would be no more illuminating than the first. Therefore, a cross-sectional survey was selected.

The final stage in the survey design was to determine how to conduct the survey: by questionnaires, interviews or a combination of these techniques. The trial run of the Preliminary Questionnaire helped to answer this question. These questionnaires were completed poorly and it was during discussions with engineers that had completed them that it was discovered that a form could not identify all the issues. The outcome of these discussions was the decision that the project engineers had to be interviewed to gain a true insight into the problems. However, a questionnaire still provided a good basis for the interview and this resulted in the modification of the initial questionnaire for that purpose, giving rise to the Preliminary Questionnaire in Appendix A.

3.4 Conducting the Survey

The survey was confined to the BAE SYSTEMS projects which were members of the Dependable Computing Systems Centre[4] [DCSC 2007]. Five BAE SYSTEMS divisions took part in the survey, Airbus (Filton), Avionics (Plymouth), MBDA (Filton), CSS & Programmes (Brough and Warton). From each of these company divisions the following product programmes took part:

- Airbus (Filton): A380 IMA, A380 Fuel Systems
- E&IS (Electronics and Integrated Solutions): Merlin, Sensors
- MBDA (Filton): Sea Dart, ASRAAM
- CSS & Programmes (Brough): Tornado, Gripen
- CSS & Programmes (Warton): Eurofighter/Typhoon

Nineteen engineers were interviewed individually in the course of this survey. Their experiences ranged from an engineering graduate with six months

[4] The Dependable Computing Systems Centre (DCSC) was founded in 1991 by BAE SYSTEMS, the University of York and the University of Newcastle. The DCSC performs research into dependable computing systems in conjunction with the BAE SYSTEMS companies and its affiliated joint ventures. The Traceability Practice Survey was conducted as part of the DCSC research programme.

experience to a head of department who had over twenty years experience of aerospace development.

Before every site visit, the site survey sponsor was sent a general product questionnaire (Appendix A). This questionnaire had two purposes. Firstly, it helped the sponsor in selecting a suitable project and secondly, it allowed the development of more targeted interview questions. The product questionnaire covered the following four areas:

- The first area of questioning was related to the product. These questions were intended to gain an overview of the product and its complexity.
- The second area of questioning related to determining the project's organisation.
- The third section of the questionnaire investigated how the project communicated.
- The final section of the questionnaire looked at what tools and protocols the project teams were employing to overcome the problems related to Traceability.

An interview schedule was drawn up from the information gathered from the returned questionnaires. The interviews were conducted during a number of site visits that occurred during 2002. The interviews were structured to gain the maximum contribution from the engineer and were based on ideas presented in standard texts [Babbie 1990;Leong and Austin 1996;Robinson 1993]. The interviews were conducted in a relaxed, informal manner that helped to put the engineer at ease and helped to dispel any ideas of the interview being some form of quality audit.

Each interview started by the interviewer describing the aims of the survey to the engineer, which involved giving a quick overview of the DCSC. This was followed by the interviewer describing his background, engineering interests and how they related to the survey. Once a rapport had been established, the engineer was asked to describe his job function, his department and finally the product that he was currently working on.

The interview then concentrated on the Traceability tools employed on the project. The engineer was encouraged to describe the benefits and pitfalls of these tools and the environment that they were used in. In the final phase of the interview, the engineer was asked for ideas to improve his Traceability tool set or working environment. The engineer was invited to *"think out of the box"* by the interviewer stating that he, the engineer, had "three wishes" that could be used to bring about the ideal Traceability tool and working environment. This phase of interview often proved to be most fruitful. The topics discussed often related to deficiencies that had been covered earlier in the interview. The interview was finished by the engineer being thanked for his contribution.

In the course of the survey, a total of fifteen hours of interviews were completed, with the average length of an interview being approximately three quarters of an hour. Throughout the interview, the interviewer would record informal written notes that were later transcribed. This technique proved to be more successful than recording, as many engineers appeared to be hampered by the presence of a microphone.

3.5 Survey Results

The main conclusion of this survey was that "best practice" is not a simple matter of selecting the correct Traceability tool or adopting a new method of working. The survey raised a number of factors that influenced Traceability practice.

- Traceability Tools
- Development Practices
- Development Communications
- Cost/ Benefits
- Organisation & Culture

- Traceability Comprehension.

3.5.1 Traceability Tools

The projects surveyed employed four different tools for Traceability: DOORS[DOORS 2007], Cradle [Cradle-5 2007], Requirement Traceability Management (RTM) [RTM 2007], and Product Version Control System (PVCS)[PVCS 2007]. Only RTM and DOORS are dedicated Requirements Traceability tools, while PVCS is a software configuration tool and Cradle is a software engineering tool that is based on the Ward-Mellor method of software development.

The majority of the surveyed projects only employed Traceability tools for product verification. This use was highlighted by the method of deployment; on many of the surveyed projects, the tools were maintained by a quality team that was separate from the main development teams. This bias towards product verification role was confirmed by a number of engineers who stated that Traceability tools had no role to play in the development process and that these tools were only a means of checking that all the *"i's had been dotted"*.

All the engineers surveyed expressed dissatisfaction with their Traceability tools, with data entry being the most commonly quoted area of dissatisfaction. The need for engineering data to be specially transcribed for the Traceability tools often caused backlogs in data entry. These delays were often further increased due to the lack of personnel who had the required training to manipulate and format the traceability data. The resulting slow data entry process often caused Traceability database to be out-of-sync with the development process and as a result, the Traceability data was mistrusted by the development engineers. A number of projects tackled this problem by having the data entry performed by a dedicated team (usually a team with a product quality function) who understood the traceability tools. It was found that though this type of team organisation relieved the development teams of the data entry burden, traces were not recorded accurately and the data was still out-of-sync with the development process

How the tools displayed the Traceability data was heavily criticised by the surveyed engineers. One development engineer stated, *"You see everything or nothing. You get swamped by the diagrams"*. This quote summed up the general feeling among the surveyed engineers. The issue of data presentation caused many development engineers to refrain from using a Traceability tool unless they had had specialised training in the use of the tool and therefore could navigate the Traceability data effectively.

A number of engineers stated that the Traceability tools force them to work in an un-natural way, for example, one tool required all configured items to be referenced by a number rather than by a textual name. This numeric indexing caused confusion and time to be wasted in decrypting the numbers back into text.

Traceability tools were also found to be lacking in the narrow selection of source media that could be traced. All the tools surveyed employed text as a base media for Traceability, therefore these tools were are unable to offer any Traceability functionality for diagrams, plans or mathematical algorithms. A number of projects partly solved this problem by storing the changed diagram plan or algorithm in a separate configuration database, such as PVCS, and then recording a reference to the changed item in the RT tool.

The Traceability tools in the survey were found to be poor in the development of collaborative products. It was often very difficult, due to firewalls and or security policies, for a co-located subcontractor to view the required subset of the Traceability data.

3.5.2 Development Practices

It was found that how system requirements were created, refined and implemented had a major bearing on Requirements Traceability. For example, engineers stated that the way requirements were written often hindered Requirements Traceability. A common complaint made by design engineers was that the requirements documentation was written in such detail that these documents were in practice pseudo design documents. These over elaborate requirements documents often caused confusion about what the requirements really were and how the requirements should be mapped onto a design. The following quotes made by development engineers summarise the problem:

"The requirements documentation is too complex, the granularity is too fine"

"They (requirements engineers) have done my job for me".

"Why did they (requirements engineers) want it to be implemented that way?"

Requirement Traceability was found to be confused when a set of functional derived requirements was mapped onto an object-oriented design (OOD). Engineers claimed that it was difficult to determine the correct level of mapping, for a requirement may be satisfied by the parent object or by one or more of the inherited specifications. This mapping confusion also affected software testing as it was difficult to determine which objects should be tested against which requirements. The engineers, who stated a view on this topic, stated that the functional requirements to OOD mapping issues could be partly solved by the adoption of an informal local mapping standard that dictated how functionality was related the OO design.

3.5.3 Development Communications

The way functional teams within a project communicated was shown to have an effect on Traceability. The survey demonstrated that the main method of communication between cooperating functional teams, such as systems and software design, was mostly by the regular issuing of interface documentation. It was found that in many projects these interface documents were not updated regularly. Engineers would often work from personally updated annotated copies of interface documents. Where this occurred, traceability between the requirements and design became confused. Without any traceability, the impact of changes to the interface documentation was not always determined and negotiated with the affected teams. The engineers referred to this as *"Throwing the Problem over the Wall"*.

Many of the projects surveyed demonstrated a degree of subcontracted engineering. It was stated by engineers, employed by the subcontractors, that stale interface documentation was a major issue. This problem of stale documentation caused many engineers to bypass the formal route of communication and to informally contact their colleagues to obtain the up-to-date information. These engineers used this informal information to annotate their original issued documents, therefore losing all traceability.

Product testing was found to be affected by stale interface documentation. Product test engineers interviewed stated that product integration was proving to be more difficult due to subcomponents not functioning to the current interface requirements. This was often due to a subcomponent being developed from a set of stale interface requirements. Poor impact analysis on interface requirement changes was also quoted as the cause of product integration testing issues. Test engineers also stated that it was difficult to obtain "background" information on an interface requirement for example, the reasoning or justification behind a requirement and this often lead to poorly scoped tests being applied.

3.5.4 Perceived Costs and Benefits

All the surveyed Traceability tools were labour intensive and required specialist knowledge to enter or configure the data. A common opinion of the managers surveyed, was that Traceability data entry was hindering the development process. These managers perceived the labour costs to be too high and the benefits too low. These views were further coloured by the perception that Traceability did not contribute the general development process and was only a quality control tool.

Most of the engineers interviewed were disaffected with their Traceability process and considered it to be a burdensome task that did not have any direct benefits.

3.5.5 Organisation & Culture

Project organization and team size was found to have a bearing on how Traceability was performed. Formal Traceability practice was found to be non-existent for projects that had small teams based in one location. These projects often implemented an informal RT process that relied on verbal communications, engineer's product knowledge and hand annotated documentation. However, all the multi-national projects surveyed, demonstrated a formal tool supported Traceability process.

The type of project also had a bearing on Traceability practice. New projects were more likely to have implemented a Traceability process, while projects that were updating or modifying existing projects often had no formal Traceability practice.

For some of the projects Traceability was considered a burdensome process that hindered the development of the product. In such a culture, it was found that Traceability was sidelined to an offline process, referred to by one engineer as a *"quality, rubber stamping process"*. Where this occurred, the Traceability database rapidly became out of date with the development process. It was also found that such offline traceability databases often contained a number of errors that could be attributed to the data entry engineers lacking the relevant project knowledge.

3.5.6 Traceability Comprehension

The survey highlighted a wide range of understanding on the benefits of Traceability. A number of the engineers interviewed stated that the primary use for Traceability was for *"product quality control"*. When asked to elaborate on the term *"quality control"*, they often replied with *"change or version control"*.

This limited understanding of Traceability is one the main driving forces behind tool selection and associated Traceability practices.

The lack of Traceability understanding was not applicable to all the projects surveyed, for there were a number of notable examples. The Gripen (Brough) team that developed a Traceability tool based on SGML to manage requirements across two organisations (BAE SYSTEMS and SAAB). The Avionics team (Plymouth) developed a Traceability tool based on DOORS that helped them develop and maintain a number of variants on a common sensor. The MBDA ASRAAM project traceability database recorded additional domain information, such as references to safety arguments and functionality warnings, to help in change impact analysis.

3.6 Reflections on Traceability Practice

The main theme that arose from the BAE survey was the perception by development engineers and their line management that Traceability did not provide any benefit to main development task. Many of the surveyed development engineers considered it a hindrance to their main task and were unsure of the benefit of this data to the project as a whole. These views were also found by Gotel in her survey [Gotel 1995]. The most common reason given by many development engineers on why the process of recording Traceability hindered their main development tasks was the extra effort involved in data transposition and entry. Again, both Gotel and Ramesh obtain similar responses. It can be argued that if Traceability was directly beneficial to these engineer's development tasks, they would have altered their tools and work practices to resolve the problems related to recording traceability data. Many of the tool and data recording issues raised in the BAE survey may well be no more than excuses, which justify the low priority that these engineers have placed on Traceability due to it not providing any benefit their immediate work tasks.

3.7 Previous Traceability Practice Surveys

The studies performed by Ramesh and Gotel are most widely cited in the literature. Gotel [Gotel 1995;Gotel and Finkelstein 1994] surveyed the views of engineers whose work area covered all aspects of development, maintenance and management. The aim of this survey was to determine the issues in the implementation of Requirements Traceability. Ramesh [Ramesh 1998] reported on a study of Traceability practitioners from a wide range of organizations. The aim was to identify how environmental, organizational and technical factors influence the adoption and use of Traceability.

Gotel reported on a survey of practitioners whose work area covered all aspects of development, maintenance and management. The aim was to understand why Requirements Traceability was a widely reported problem area despite many advances in research and tool development. The survey consisted of two questionnaires and two informal interview sessions. The first questionnaire was distributed to 80 practitioners (55 returned), the second one to 39 practitioners (31 returned). Two large informal interview sessions were performed with the questionnaire respondents that lasted for one and half hours each. From this empirical investigation Gotel [Gotel and Finkelstein 1994] identified the following sources to the Requirements Traceability implementation problem:

- Lack of common definition for the purpose of Requirements Traceability.
- The existence of multiple incompatible and fragmented documents, form distributed sources, with no clear relationship.
- The inability to handle the increasing amounts of documentation
- Change, and the slowness with which all its ramifications are taken into account, which leads to numerous versions of documents in various stages of evolution.

- The lack of an end-to-end Requirements Traceability process, plus the absence of a specified Requirements Traceability job description, thus leading to Requirements Traceability mismanagement.
- The involvement of too many, often uncooperative people, with inadequate expertise and individual agendas.

The second extensive study on Traceability was performed by Ramesh [Ramesh 1998]. This study involved practitioners from U.S. government system development, program management and testing, pharmaceutics, utility, telecommunications, aerospace, electronics, automobile, and software consulting/contracting. The aim was to identify how environmental, organizational, and technical factors influence the adoption and use of Traceability. This survey was performed in three phases. The first phase, a pilot study, consisted of surveying the views of 58 Master Students whose areas of expertise included shipbuilding and aviation maintenance. Ramesh did not state how many of these students had experience in software development. This pilot study six focus groups, seven verbal protocols and six structured interviews. From this data, Ramesh developed the initial version of traceability meta-model. The second phase of the study consisted of querying tool vendors on the traceability functionality of their tools. Ramesh states that his findings were similar to that of the INCOSE tool survey[5] [INCOSE 2007].

From this data, Ramesh stated that he determined the shortcomings of the current tools. The final phase of the study comprised of 30 focus group discussions in 26 organisations that included aerospace, hardware development, pharmaceutical,

[5] The INCOSE tool survey is not a truly independent survey as the data on the traceability functionality is provided by the tool vendor and may not have been verified.

systems integration and telecommunications. From this data, Ramesh developed the profile for high and low traceability users (Table 1).

Finally, Ramesh argues how the traceability meta-model, developed in the pilot study, would have be adjusted to suit the needs of these two groupings. The published results do not give any indication of the problems facing engineers.

Characteristic	**Low-end Traceability User**	**High-end Traceability User**
Number of Organisations in study.	9	17
Number of Participants	54	84
Typical Complexity of System	≈1000 requirements	≈10,000 requirements
Traceability Experience Level	0 to 2 years	5 to 10 years
User definition of Traceability	Document transformation of requirements to design.	Increases the probability of producing a system that meets all customer requirements and will be easy to maintain
Main Application of Traceability	Requirements decomposition Requirements Allocation Compliance Verification Change Control	Full coverage of the lifecycle, including user and customer; captures discussions issues, decision and rationale; capturing traces across product and process dimensions.

Table 1 Characterisation of Low and High Level Traceability Users

An earlier publication by Ramesh and Edwards [Ramesh et al. 1995] on the lessons learnt from implementing a traceability system is more informative. In this paper, Ramesh and Edwards describe the following problems in implementing a traceability process.

- The burden on the development process due to traceability data entry and transposition.
- High costs - CASE tool training, employing dedicated staff.

- Poorly structured documentation – leading to confusion over what should be traced.
- Office Politics – The fear of staff that a traceability systems may be employed to assess their productivity

3.8 Comparison of Surveys

The disappointing outcome of the traceability practice survey was that it found similar problems to what Gotel[Gotel 1995] and Ramesh [Ramesh, Stubbs, Powers and Edwards 1995] both reported on over ten years ago. It appears that recent advances in computing over the last ten years, such as the internet and vastly increased computing power, have done little to alleviate these problems.

All three studies reported a wide range of Traceability comprehension. Ramesh [Ramesh and Jarke 1999a] employed this fact to classify his users. This was reported by Gotel as lack of common definition for the purpose of Traceability. We also found a wide range of understanding and that this often resulted in managers and project leaders questioning the true cost benefits of Traceability.

Tool related issues were reported by all three studies. These issues ranged form the inability of Traceability tools to cope with a diverse set of media, the high costs incurred in training staff in the use of these tools, to the burden of transposing data for these tools.

The issue of poor communications between development teams affecting Traceability was highlighted by Gotel and our survey. Both surveys found that stale interface documentation, due to slow uncoordinated changes, was a major problem in implementing Traceability. The issue of poor communications, in the form of poorly structured documentation was also raised by all three surveys. All three studies highlighted how poor communications between development teams made end-to-end Requirements Traceability difficult to achieve in practice.

The next chapter examines in more detail the common issues raised by these surveys such as, the burden of data entry, who records and who benefits from traceability data.

Chapter 4 The Traceability Benefit Problem

4.1 Introduction

This chapter builds upon Chapter 3 by reviewing the themes present in the BAE traceability practice survey and the surveys performed by Gotel[Gotel 1995] and Ramesh [Ramesh et al. 1995]. From this analysis, an argument is developed which states that one of the major causes of poor traceability practice is the lack of benefit that it provides to the current development process: this is referred to as the Traceability Benefit Problem.

4.2 The Burden of Data Entry

The burden of data entry and transposition was commonly cited in all three surveys by engineers as being a hindrance to their development task. Many of BAE SYSTEMS projects assigned a low priority to the task of recording traceability information. To reduce the burden of entering traceability information some of the BAE SYSTEMS surveyed projects separated their traceability process from the main development process. In these projects the traceability process was undertaken by a dedicated quality team, which had an understanding of the traceability tools and techniques. Though this organisation alleviated pressures on the development teams, it was found not to improve the quality of the traceability information. It was observed that the number of wrong or bad traceability relationships increased, and the traceability data was out-of-sync with the main development process.

A way of reducing the data entry burden is to automate the process of generating the trace relationships between documents. There have been a number of attempts to achieve automatic trace generation. One of the simplest methods of trace automation is use of a standard naming convention. This allows traces to be generated between artefacts that have the same key word in their name. The problem with this approach is that the naming convention has to be strictly adhered to. Grunbacher [Grunbacher 2006] described a traceability system which successfully employed this method in a small example by the use of input agents which enforced the naming convention.

An interesting approach to automatic trace generation was put forward by Egyed [Egyed 2005], who employed code call analysis in conjunction with test scenarios (a collection of tests) to establish the relationships between requirements and code and requirement interdependencies. Egyed established a relationship by executing a test script that exercised a given requirement on a code analyser (IBM Rational Pure Coverage). The code analyser recorded which items of code were called for that requirement test script. From this information, it possible to say that there is a relationship between the called code and the tested requirement. The problem with this approach is that a combination of tests are required to be performed to identify the true relationships. However, even with relatively few test scenarios this method can highlight dependencies between requirements, although it is questionable whether this is a truly automated process when a large amount of effort is required to the produce the test scenarios.

A more general approach employs domain information, such as key words and phase, and search engine technologies to identify relationships between documents. This approach is similar to performing a search using a search engine such as Google. Instead of the keywords being highlighted by search engine links are generated between documents that contain the keywords. There are number of examples of link generation systems, the Advanced Artefact Management System (ADAMS)[De Lucia et al. 2004], Requirements Tracing On-Target (RETRO) [Hayes et al. 2006] and Marcus et al [Marcus and Maletic 2003], Antoniol et al [Antoniol et al. 2002] on recovering traceability links between code and documentation.

All these systems employ a technique called Latent Semantic Indexing (LSI) to identify sections of documents, which may be related and hence are candidates for generating a traceability link. Traditional keyword searches, for example grep, look for the presence of a word or phase and documents are only retrieved if a match is found. Latent Semantic Indexing (LSI) tries to improve on this by looking for groupings of the key words. LSI assumes that there is some underlying or "latent structure" in the word usage that is partially obscured by variability in word choice, and make use of statistical techniques to estimate this latent structure. In addition to analysing the keywords a document contains, this method examines the document collection as a whole, to determine which other documents contain similar key words. LSI considers documents that have many words in common to be semantically close (a potential trace relationship), and ones with few words in common to be semantically distant. Supporters of this search method claim it correlates surprisingly well with how a human being might classify a document collection. For example, a search of a historical database that employs LSI indexing for *"1944 Normandy Invasion"* may select documents related to the Second World War invasions of Normandy that contain the key words followed by a number of documents which are semantically more distant such as the documents on the Bayeux tapestry and the Norman invasion of England in 1066. In a similar way the traceability link generation systems return a number of links ranked on their semantic distance from the key words. Filters, such as a simple threshold based on the link semantic ranking (e.g. taking the first 50 links), can be employed to reduce the number of links.

To demonstrate the performance of a traceability link generator, two metrics are employed. Trace Recall (Equation 1) is the percentage of correct links identified from the set of correct links. If a recall value of 1 is obtained then all the correct links have been identified, though there could be recovered links that are not correct.

$$recall = \frac{\sum_i |correct_i \cap retrieved_i|}{\sum_i |correct_i|}$$

Equation 1 Trace Recall

Trace Precision (Equation 2) is the percentage correct links identified from the total number of links returned. If the precision value equals 1, it means that all the links identified are correct, though there could be correct links that were not recovered.

$$precision = \frac{\sum_i |correct_i \cap retrieved_i|}{\sum_i |retrieved_i|}$$

Equation 2 Trace Precision

Researchers have applied optimisation or filtering techniques to reduce the number of links return by a LSI search. Weak optimisation results in high recall but with low precision and strong optimisation results in low recall with high precision. Though these researchers applied different optimisation techniques and had different documentation sets, they produced similar results, with the best optimisation compromise producing an approximate recall of 80% with a precision of 50%. Though these results are promising, it is accepted that LSI based systems can not replace the software engineer in the task of maintaining traceability links during software evolution [De Lucia et al. 2004].

4.3 Establishing a Relationship

To explain why separate traceability teams and LSI search engines have problems determining traceability links we should consider some of the processes involved in performing a development transformation, such as developing a software design from a set of requirements.

A requirement can be defined in a number of ways, though the most popular is still by the means of a natural language. Natural language can be notoriously ambiguous and often requires a degree of interpretation by the reader. These areas of ambiguity will often be resolved by peer group and inter-group (requirements team and design team) discussions [Weinberg 1998]. To clarify an ambiguity a design engineer may employ different terminology to that which is expressed in the requirements. This may result in a LSI search engine failing to establish a link or in the best case establishing a low ranking link. The counter argument to this problem is that its resolution lies in the rewording of the requirements, though in practice, unfortunately, this does not always occur.

The development of a software design can be described as the application of a design method (a set of rules and conventions) to the set of requirements. These rules and conventions have to be rigorous enough to produce a coherent design, yet flexible at the same time to allow for different implementation strategies. Therefore, the application of a design method to a requirement set will result in a set of valid designs. Engineers impose their experiences onto a design [Weinberg 1998]. Design "templates" which have worked well in the past are often reused. Therefore, different groups of engineers may produce different designs depending on the outcome of their discussion and previous experiences. During the design process "House Styles" often evolve, for example the naming of variables, functions, files etc. These local practices may be defined in local standards documentation, but their enforcement is achieved only by peer group pressure. Therefore, the consistency of a design will be influenced by how well the local practices are complied with. Antoniol et al [Antoniol et al. 2002] stated that this information will have to be captured and incorporated into the filtering algorithms to improve the recall and precision of LSI based link generation systems.

The outcome of these observations is that the production of a design is not a simple transformation process. There are a number of development factors which are often not recorded, as described above, which influence the final design. The degree of influence of these development factors on the final design is difficult to quantify. It can be argued that without the tacit knowledge these development factors may not be able to record the relationships between the design and the requirements accurately. This is what we observed in the BAE traceability practice survey with respect to the use of separated teams in the recording of the traceability information. The presence of non-recorded development factors also curtails the accuracy of search engine based technologies, such as LSI, as it may not be possible to capture the semantics related to these factors. This view is confirmed by De Lucia et al [De Lucia et al. 2004] who state that such systems are unlikely to replace an experienced development engineer for the determination of trace relationships.

In summary, the presence of non-recorded development factors implies that only the engineers directly involved in the development transformation process (such as the development of a design from requirements), and who have therefore gained this tacit knowledge, can accurately record the development transformation traceability relationships.

4.4 Traceability Benefit Problem

The previous conclusion leads to a conflict. The recording of traceability information is best performed by the engineers directly involved in the development process; yet the BAE Survey (Chapter 3), Gotel [Gotel and Finkelstein 1994] and Ramesh [Ramesh 1998] have found that it is precisely these engineers who seem to obtain no direct benefit in performing this task. The BAE Survey highlighted that this lack of perceived benefit resulted in the development engineers to assign a very low priority to traceability tasks. The outcome was traceability data that was incomplete, inaccurate and out of date. This can be summarised as the Traceability Benefit Problem.

Traceability Benefit Problem

The recording of traceability information is best performed by the engineers directly involved in the development process; it is precisely these engineers who seem to obtain no benefit in performing this task. This lack of perceived benefit causes the development engineers to assign a very low priority to traceability tasks. This results in data that is incomplete, inaccurate and out of date.

Therefore, to overcome this problem the recording of traceability data must provide immediate, tangible benefits to the engineers performing the current development process.

The following chapters consider how the Traceability Benefit Problem may be overcome. The next chapter describes in detail how one of the surveyed projects addressed the Traceability Benefit Problem by developing a traceability system that was beneficial to the development engineer, the project management and the customer. The lessons learnt from this case study form that basis for a generic solution, the Traceable Development Contract, which is described in the latter chapters of this thesis.

Chapter 5 Automotive Sensor Case Study

5.1 Introduction

This chapter describes in detail how one of the BAE SYSTEMS surveyed projects developed a traceability system that addressed the Traceability Benefit Problem. The traceability system and development process were developed by BAE Electronics and Integrated Solutions and the analysis of the project traceability data and the conclusions drawn from that analysis are part of the contribution of this thesis. The chapter describes and illustrates with project data the development process and traceability system. Finally, the chapter describes the benefits the traceability system provides to development engineer, the project management and the customer.

5.2 Automotive Sensor Case Study

One of the companies surveyed, BAE SYSTEMS E&IS (Electronics and Integrated Solutions), addressed the Traceability Benefit Problem by developing a Requirements Traceability system which is integral to their development process and provides direct benefits to both the engineers performing the data entry and the business. This division of BAE SYSTEMS produces a range of sensors that measure the movement and direction of a vehicle. These sensors are employed in Electronic Stability Program (ESP) sensor packages (Figure 5-1)

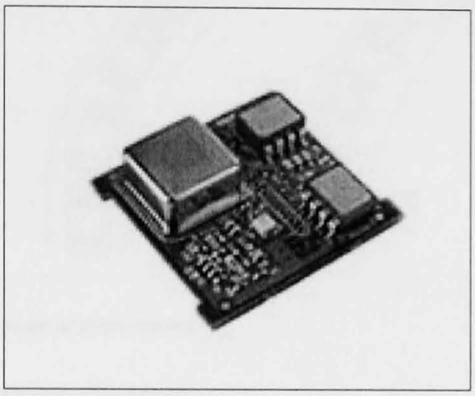


Figure 5-1 A typical ESP sensor package

Many modern vehicles have an ESP system that reduce oversteer or understeer (Figure 5-2). These systems stop the vehicle going into a spin by applying the brakes and or controlling the power to the drive wheels. The heart of these systems is the yaw velocity sensor. The yaw sensor acts like a compass; it constantly monitors the exact attitude of the car and registers every incipient spin. Other sensors report how high the current brake pressure is, what the position of the steering wheel is, how great the lateral acceleration is, what the speed is and how big the difference in wheel speed is. Whenever handling becomes instable, the necessary commands are executed and the vehicle is brought under control in a fraction of a second.

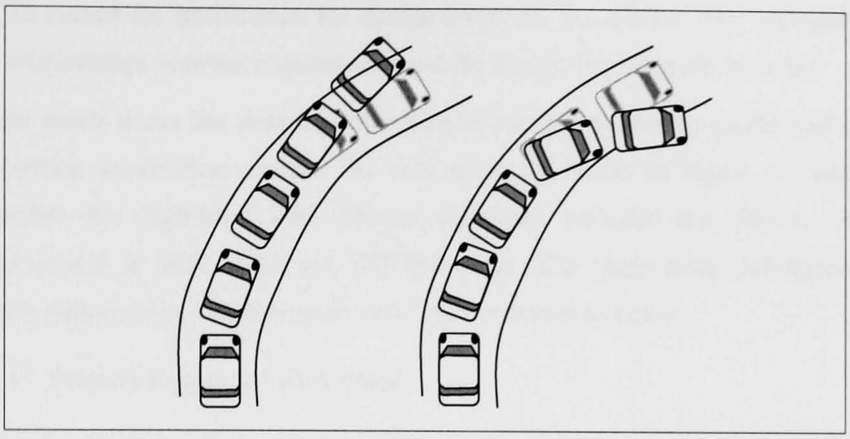


Figure 5-2 Understeer and Oversteer

5.3 Development Process

Though these positional sensors have common functionality, each vehicle manufacturer has a different set of requirements and this means that a number of different variants of a common sensor are produced. The software for the positional sensors is developed and maintained by a small team (four to five) of specialist engineers. Each engineer has an assigned role, though they can be called upon to change their roles. To aid these engineers in their tasks, a Requirements Traceability system was developed to provide information on each sensor variant and also to support tenders for new sensors. From the outset, the traceability system was design to answer following business needs:

- To show that all of the customer requirements have been satisfied. To achieve this, traceability relationships from the requirements to test procedures and related test results are recorded.
- To identify which parts of the generic sensor design are required to be changed to produce a customer variant. To achieve this, traceability relationships are recorded from the requirements to design

- To record the justification for design decisions. To achieve this, traceability relationships between requirements and the design decisions are recorded.

These needs drove the design of the Requirements Traceability model and the supporting engineering process. The data model, as shown in Figure 5-3 which describes the high-level data objects and links between the objects, was implemented in both RTM and DOORS tools. The engineering development phases supported by the data model and tool are described below.

5.3.1 Prepare Inputs for a Proposal

This development phase is concerned with capturing and reviewing the customer's requirements, and is divided into a number of tasks. The first task is to identify and capture requirements from the customer's documentation. Any queries on the requirements are recorded and raised with customer. The requirements are reviewed with respect to compliance with existing products, and from this information a compliance matrix (requirements vs. current product) is generated. This matrix is used to select the most suitable product to be a basis for the customer's new variant, and gives an indication of the extra work required to produce the new variant.

5.3.2 Manage, Analyse, Develop System Requirements

This phase starts once a contract has been signed. The model and supporting processes are employed to control the introduction of new requirements and the modification of existing requirements to prevent requirements creep. The main task of this phase is the development of the customer's new requirements. For each of these requirements, a development risk grading is assigned and a verification method is identified and recorded. The compliance matrix is regenerated to ensure that the new product complies with the customer's requirements and that there is a verification method for each requirement.

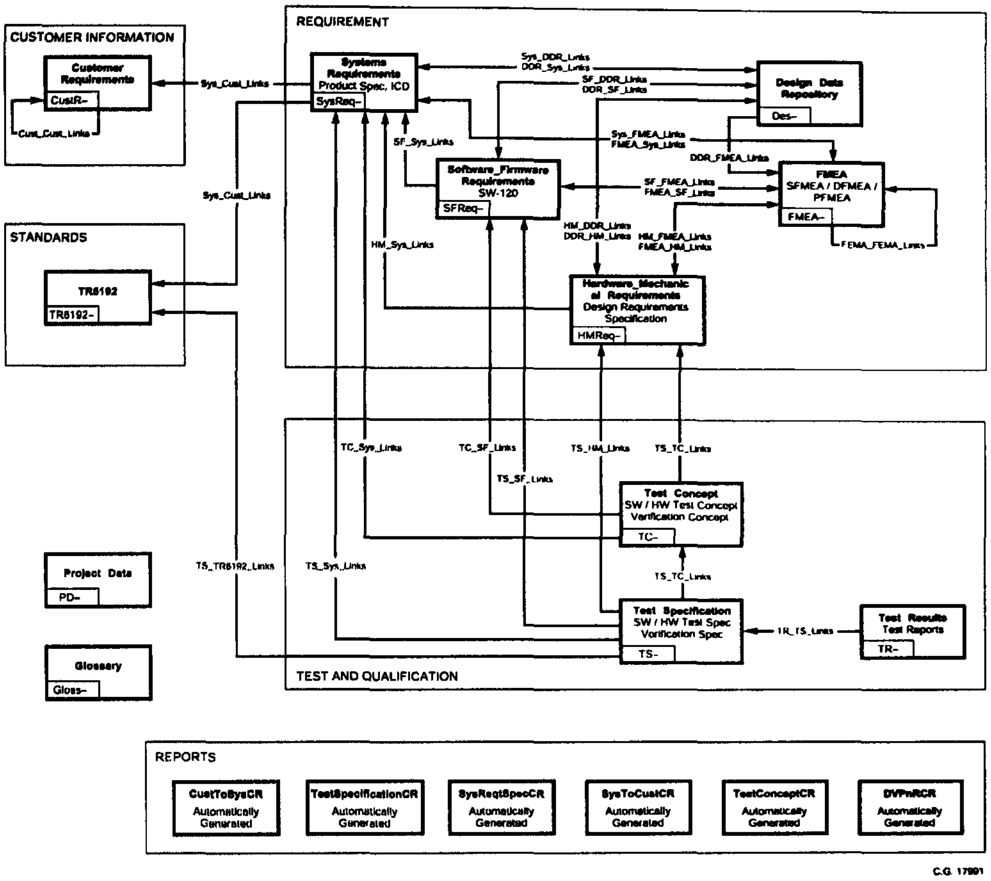


Figure 5-3 Traceability Data Model (BAE SYSTEMS E&IS)

5.3.3 Design

The design phase enables the recording of design decisions, the member of staff who made the decision and how it is related to the requirements. A Failure Modes and Effects Analysis (FMEA) also allows the recording of failure mode estimations and how they relate to design decisions. The accepted level for the total failure mode estimation is specified by the customer. This recorded design information traceability enables the assessment of the impact of any change in requirements.

5.3.4 Prepare Test and Qualification Procedures

The data model enables the recording of relationships between requirements and test procedures. Test procedures describe the validation testing at a high level of abstraction (recorded under data model entity: Test Concepts). A test procedure is decomposed into a number of test cases that address a lower level of abstraction and are in turn decomposed into a number of test steps (both recorded under data model entity: Test Specification). The test steps describe in detail the nature of the test and the expected result. From the information in the traceability system, it is possible to generate a document that describes the test description required to qualify a product against the customer's requirements.

During the qualification phase the defined test steps are run and the results recorded. Having traceability from the requirements to test steps and their related results in the data model, via test cases and test procedures, allows the verification information to be generated quickly and accurately. This allows the rapid sign-off or acceptance of the product by the customer. In addition, as verification evidence is accrued during the project lifecycle, the degree of compliance to the original requirements can be closely monitored by management to ensure that the project remains on track for success.

5.4 An Illustration of the Traceability System

Having described the traceability data model and development process, this section illustrates the benefits obtained from traceability by describing the development history for a product variant over an 18 month period. The development history is illustrated in Figure 5-4.

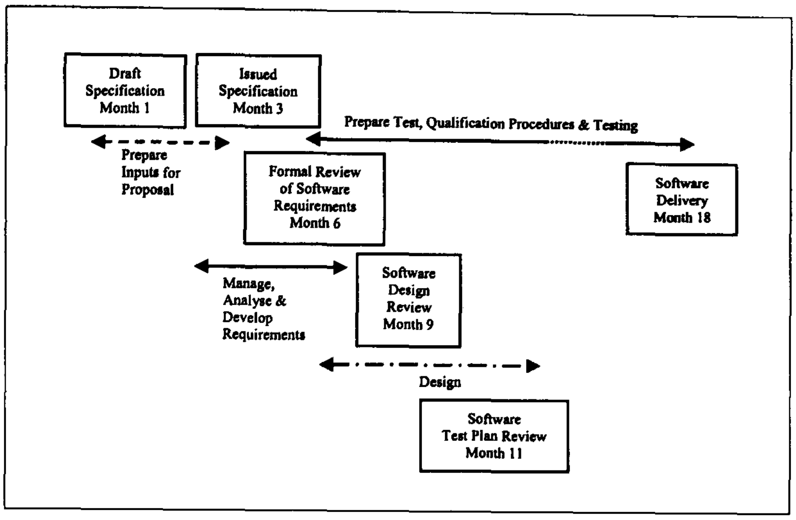

Draft Specification Month 1
Issued Specification Month 3
Prepare Test, Qualification Procedures & Testing
Prepare Inputs for Proposal
Formal Review of Software Requirements Month 6
Software Delivery Month 18
Manage, Analyse & Develop Requirements
Software Design Review Month 9
Design
Software Test Plan Review Month 11

Figure 5-4 Project Milestones

5.4.1 Managing Requirements and the Customer

The development of the new product variant was initiated in Month 1, when the customer's initial draft contractual specification was received. This specification was compared against the existing specifications and related software requirements that were recorded in the traceability system.

Within a month of receiving the specification, the traceability system enabled the development engineers to answer such questions as *"what is the same, what has changed and what is new?"* with respect to the product software requirements. This analysis resulted in an initial breakdown of 38% new requirements (50 out of a total of 135), 38% unchanged, 12% requiring minor modification and 12% with unresolved issues (shown in Figure 5-5, Month 1). This information provided the engineers and their management with an indication of the potential work required to produce this new variant. During this period the engineers employed the traceability system to record any issues related to the specification.

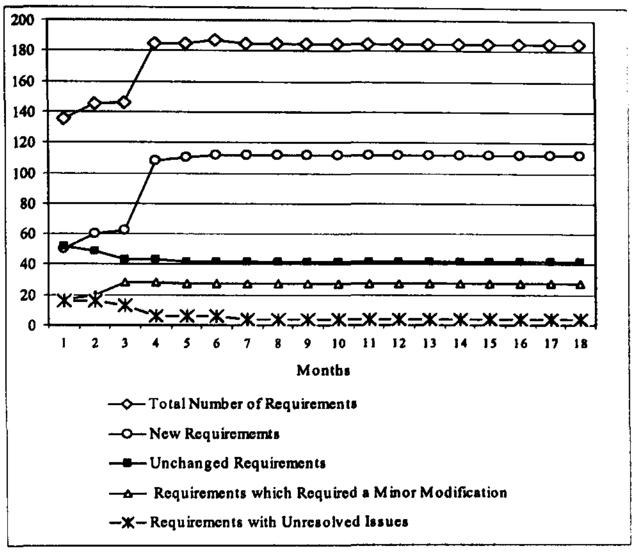


Figure 5-5 Classification of Project Requirements

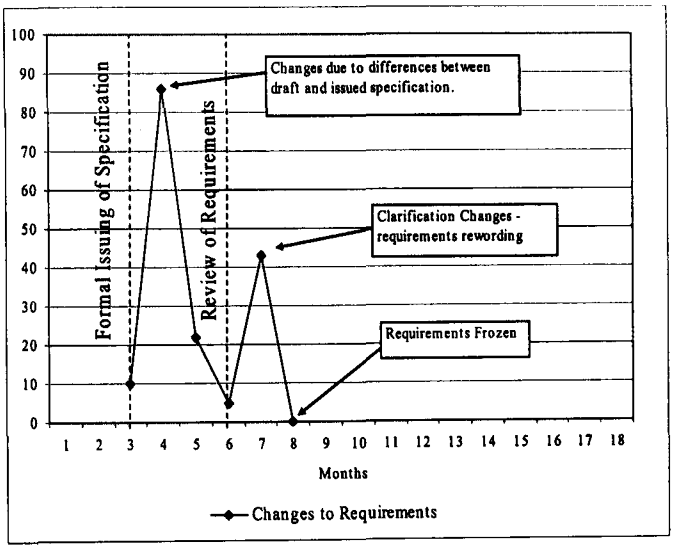


Figure 5-6 Requirements Changes

Figure 5-6 shows the changes in requirements that occurred as a result of major milestones in the development process.

In Month 3, the customer issued the final version of contractual specification. The traceability system allowed the engineers to determine which system requirements were affected by the final version, which resulted in a substantial increase in new functionality (shown Figures 5-5 and 5-6). Again, this information was employed in the revision of the estimated cost of producing the new product.

In Month 6, a formal review of the requirements was undertaken with the customer. The traceability system was employed to generate a report which demonstrated how each item in the specification was satisfied by the requirements and how it would be verified by high level qualification tests. A peer group review was undertaken of the documents by the customer's representatives and the development engineers.

This review resulted in changes to the requirements (Figure 5-6) that consisted of the rewording of selected requirements to include common terms and phrase to aid clarification between the customer and the software engineers. No new requirements were introduced at this stage and the classification of requirements remained unchanged, as can be seen in Figure 5-5.

Once the agreed changes resulting from the peer group review were completed, the specification and requirements were frozen (Month 8) for that release of the software.

5.4.2 Quantitative Management

During the requirements analysis phase the traceability system allowed the number of changes made to each requirement in that period to be calculated. This information allowed the engineers and their management to determine a time when the requirements where stable enough to progress to the requirements peer review and commence the design phase.

During the design phase, the recording of relationships between design items and requirements enabled management to estimate progress. Similar quantitative progress metrics were obtained in the testing phases by determining the rate at which trace relationships were recorded between tests, test case and test steps and the requirements.

The most important metric provided by the traceability system was determining when the development of the software was complete. This was achieved by demonstrating that all the requirements had been tested, by following the trace relationships from the requirements to tests, test cases and finally to each test step and the associated validated test result. Only when this could be demonstrated would the customer accept the product.

5.4.3 Component Reuse

As previously mentioned, the traceability systems enabled the engineers to determine which development components (requirements, design elements and tests) could be reused, by comparing the customer's specification with previous specifications and identifying related design elements (or other project artefacts). For example, it was found that, in 14 test procedures, 5 test procedures could be reused unchanged and 4 test procedures could be reused with only minor modification, giving 65% of the existing high-level tests that could be reused with at most a minor change (Figure 5-7). This level of reuse remained constant, indicating that the engineers had accurately identified the tests that could be reused at the beginning of the project.

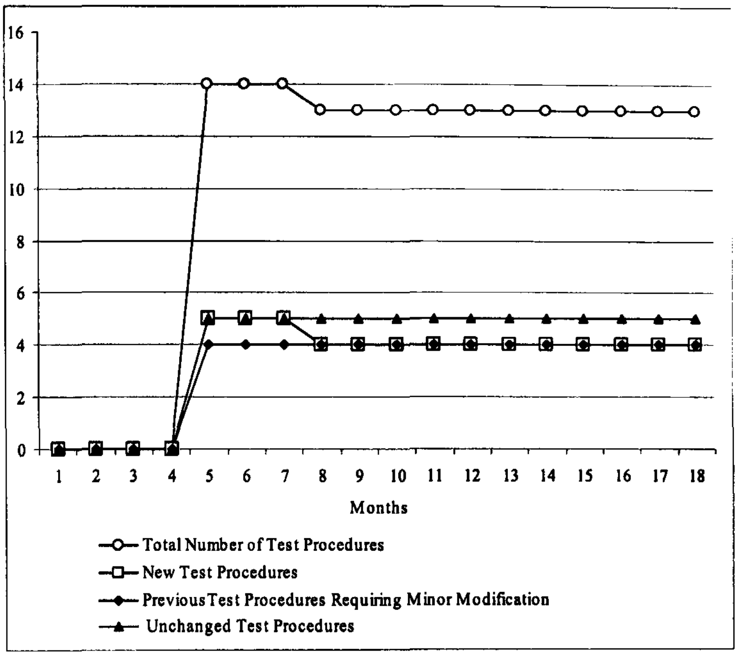


Figure 5-7 Test Procedures

In a similar fashion, the traceability system enabled the engineers to determine which test cases could be reused (Figure 5-8). It was found that 54% of test cases could be reused with at most minor changes. Again, this level of reuse remained constant indicating that the correct test case had been identified at the beginning of the project. In total, 14 test procedures, 26 test cases and 327 test steps were required to qualify the product.

The accurate identification of components that can be reused by the traceability system improves the efficiency of the development process and therefore reduces development costs. This in turn reduces the overall business risk. This is seen as a major benefit by the development engineers and their management.

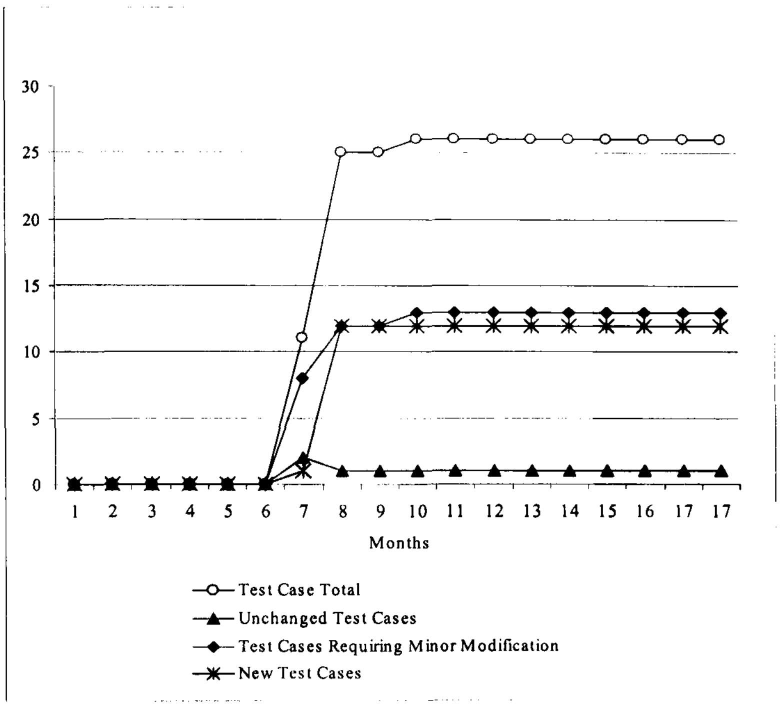


Figure 5-8 Test Cases

5.4.4 Further Examples of Reuse

The traceability system that was employed to trace the development of the sensor software was also employed to trace the development of the software for an item of avionics equipment found in an Advanced Jet Trainer (AJT), Fast Jet, Transport Aircraft and a Helicopter.

The item of equipment was originally developed for the AJT and developed further for the Fast Jet, the Transport Aircraft and finally for a Helicopter. Table 2 shows the reuse of requirements between the aircraft. By tracing from the common AJT requirements is was possible to identify common tests and code.

	AJT	Fast Jet	Transport Aircraft	Helicopter
Number of Requirements	88	131	244	131
Number of Requirements in Common with the AJT		76	68	62
% Reuse of AJT Requirements		58%	28%	47%

Table 2 AJT Requirements Reuse

5.5 Why is this System Successful?

The development engineers and their management at BAE SYSTEMS E&IS did not consider their system to be a hindrance to the development process. In fact they considered the system to be at the heart of their development process. We examine the reasons for this by considering the system from three view points.

5.5.1 The Development Engineer's View Point

The traceability system allowed the engineers to coordinate and control changes to their requirements. The trace relationships between the customer's specifications and the requirements enable the development engineers to determine and negotiate the impact of any changes to specification change. These trace relationships were employed to generate documentation which formed part of the procurement contract. These documents bound the engineers and customer together, resulting in the reduction of "*requirements creep*" (introduction of new requirements) and the elimination of "*over the wall*" (customer imposed) changes. The ability of the traceability system to allow the engineers to identify which development components (requirements, design items and tests) could be reused was also seen by the engineers as a way of improving their efficiency.

5.5.2 The Manager's View Point

Though establishment and maintenance of the traceability system required project budget, these cost were justified by the project management. The ability to identify development components that could be reused resulted in a perceived reduction in project risk. The identification of these components also enabled the project management to make better estimations of the production costs. The traceability system allowed management to estimate progress by rate of creation of traceability links between development artefacts.

5.5.3 The Customer's View Point

The traceability system does not directly increase the cost to the customer, but the presence of the system is beneficial to him. The main benefit to the customer is a demonstration of how the requirements related to his specification and how the product will be tested to demonstrate compliance with the specification.

5.6 Summary

The traceability system is beneficial to the

- Development engineer as it assists in the selection of a suitable base product and provides information that aids change negotiations.
- Manager as it helps to reduce risks and improve cost estimates.
- Customer as it provides a clear link from their specification to compliance tests.

Traceability in this project has become part of and beneficial to the development process. The traceability information is directly beneficial to the development process being undertaken and therefore overcomes the Traceability Benefit Problem. This is why this traceability system is successful.

The next chapters of the thesis examine how the lessons learnt from this case study can be employed in the development of a generic solution to the Traceability Benefit Problem.

Chapter 6 Negotiating Change

6.1 Introduction

Chapter 5 described how the automotive sensor project employed a traceability system to help the development engineers negotiate customer changes to their baseline requirements. The Traceability Practice Survey (Chapter 3) highlighted the problem of establishing and maintaining development phase baselines. During the survey, a number of engineers raised issues relating to the re-issuing of interface documentation without any consultation or negotiation (referred to as *Throwing Problem over the Wall*). This chapter examines the issue of change negotiation by considering how some common software development models deal with change. Finally, the BAE SYSTEMS Common Engineering Process Model (CEP) is reviewed as many BAE SYSTEMS development processes are based on this or a similar development model. The CEP is reviewed with respect to change negotiation and the results are related to the observations made during the Requirement Traceability practice survey.

6.2 Sequential and Iterative Development Models

6.2.1 Sequential

The waterfall development model is one of the most cited, most abused and criticised development models. The model was originally proposed by Royce [Royce 1970]. Interestingly, his paper does not mention the term "waterfall" and this term seems to have been coined due to the cascade arrangement of his diagrams that outlined a sequence of generic development phases. The waterfall model has been strongly criticised due to the apparent need to complete one development phase before embarking on the next phase. In such a model, there is no chance to negotiate change. The ability to freeze or fully complete a development phase is considered to be unrealistic by many engineers [Weinberg 1997].

To a large extent, Royce has been misrepresented as he did not propose that software development be performed in a single sequence of development phases. In his paper, he stated that there should be interaction between development phases and highlighted the issues in determining the correct development phase baseline to allow the procession to the next phase.

With respect to communication between development phases, Royce strongly promoted the use of written communication logs and interface documentation. He stated, "A verbal record is too intangible to provide an adequate basis for an interface or management decision .... An acceptable written description forces the designer to take an unequivocal position and provide tangible evidence of completion" [Royce 1970].

The V Model [IABG 2007] (Figure 6-1) which was originally developed by Industrieanlagen-Betriebsgesellschaft GmbH (IABG) in cooperation with the German Federal Office for Defense Technology and Procurement (1992) is a development of the waterfall model. The V Model is comprised of four submodels: the Software Development (SWD), Quality Assurance (QA), Configuration Management (CM) and the Project Management (PM).

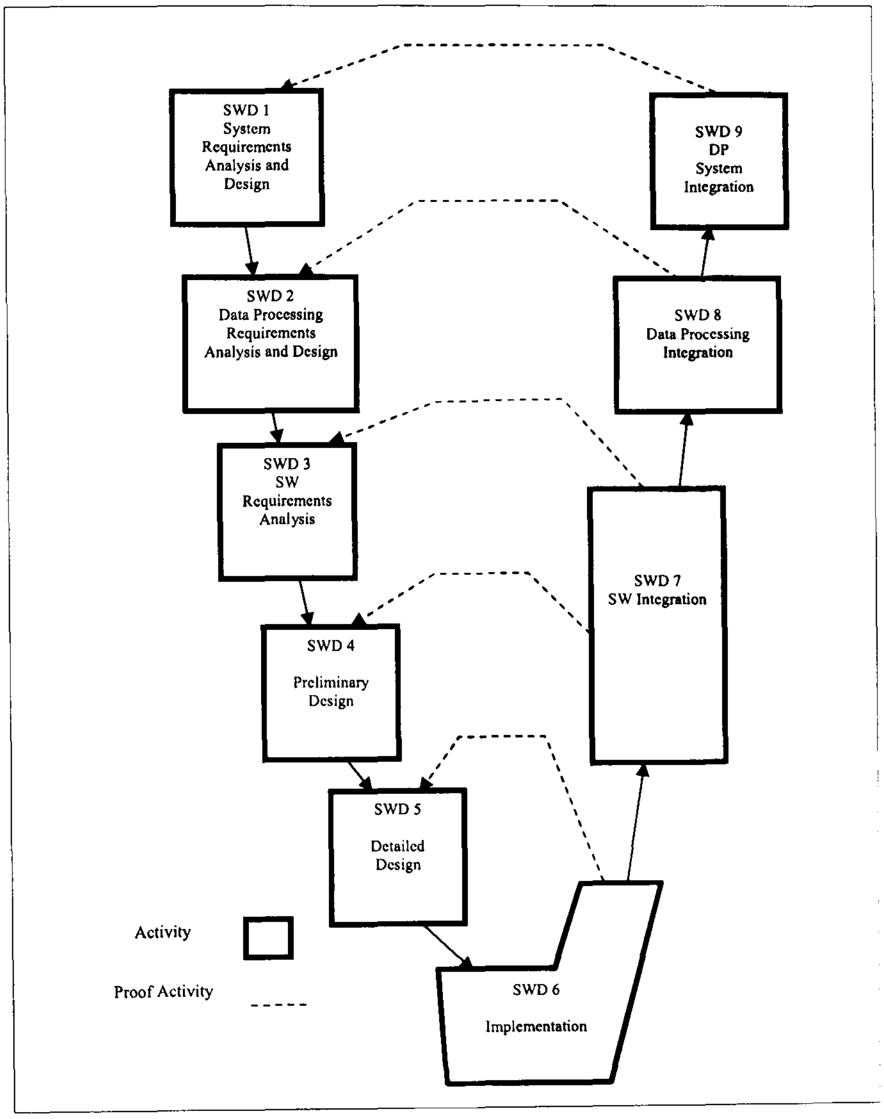


Figure 6-1 V Model –Software Development Model [IABG 2007]

The submodels are closely interconnected and mutually influence one another by exchange of products and results. The Software Development submodel (Figure 6-1) is considered to be, by most engineers, the V Model.

The Software Development submodel addresses a major criticism of the waterfall, namely that the waterfall model defers all testing to the later development stages. Such late testing often highlights problems in the implementation that are costly to fix. The Software Development submodel tackles this issue by describing the validation activities and results that are required for each stage of software development. The aim of the Software Development submodel is to spot implementation problems before they are propagated down the development process.

The Software Development submodel suffers from same issues that befall the Waterfall model in the respect of determining a suitable baseline. The model assumes that a development phase is stable and validated by testing before moving onto the next development phase. The current version of the model, V-Model XT [KBSt 2007] accepts that changes will occur. The V-Model XT document states "If a specified degree of completeness has been reached, it is necessary to follow product changes formally". The product change procedure consists of raising a change request which is evaluated and decided upon by a project change control board. This common method of change negotiation moves the decision making from the development environment to the management environment where the technical expertise may be not be as great.

6.2.2 Iterative

Beohm's Spiral Model[6] [Boehm 1986] addresses some of the deficiencies found in the waterfall model. The waterfall model assumes a progression of elaboration steps and does not accommodate evolutionary development made possible by rapid prototyping programming languages. The spiral model uses a cyclic approach to develop increasingly detailed elaborations of a software system's definition, culminating in incremental releases of the system's operational capabilities. The Spiral model can be considered a meta-model in that it is a generalisation of an incremental and iterative development model. With respect to communication and change negotiation between development teams and stakeholders, the original spiral model says little. This was considered a deficiency, addressed in the WinWin Spiral Model [Boehm and Bose 1994].

The WinWin Spiral Model employs the Theory W (Win) approach [Boehm and Ross 1989] to determine the system's next-level objectives, constraints, and alternatives. For example, the next-level could be the implementation of a number of changes that are required to be made to the existing system. The Theory W approach involves identifying the system's stakeholders and their win conditions, and using negotiation processes to determine a mutually satisfactory set of objectives, constraints, and alternatives for the stakeholders. The term "Theory" may be an overstatement, as the paper [Boehm and Ross 1989] is a collection of

[6] In his paper, A Spiral Model of Software Development and Enhancements, Boehm illustrates the Spiral model by describing the development of a Software Productivity System (SPS), which included a Requirements Traceability Tool (RTT). This tool is described in a related paper [Boehm et al. 1982]. Unfortunately, no further references can be found in the literature on how successful the RTT tool was in practice.

observations on software development which are employed to establish software project management guidelines. For example, the advice on developing a Win-Win situation involves separating the people from the problem; focusing on interests and not positions; inventing options for mutual gain and insisting on using objective criteria.

The application of Theory W to the Spiral Model resulted in the following extensions

- Determine Objectives. Identify the system life-cycle stakeholders and their win conditions. Establish initial system boundaries, external interfaces.
- Determine Constraints. Determine the conditions under which the system would produce win-lose or lose-lose outcome for some stakeholders.
- Identify and Evaluate Alternatives. Solicit suggestions from stakeholders
- Record Commitments and areas of flexibility.
- Cycle through the Spiral. Elaborate win conditions, resolve risk, develop and execute downstream plan.

The Win-Win theory and spiral model extension can be criticized as they do not deal with conflict between stakeholders, they assume that stakeholders will always cooperate, and only provide high-level guidance to solving the problem of change negotiation.

6.3 Agile Software Development

Agile Software Development developed from the principles promoted by a group of software developers who considered current development methods to be too prescriptive and restrictive. Agile Development was defined at a workshop in Snowbird, Utah, USA (2001), where software developers discussed the software development process. The outcome of the discussions was a Manifesto for Agile Software Development (Figure 6-2) [agilemanifesto.org 2007].

"We are uncovering better ways of developing software by doing it and helping others do it. Through this work we have come to value:

***Individuals and interactions** over processes and tools*

***Working software** over comprehensive documentation*

***Customer collaboration** over contract negotiation*

***Responding to change** over following a plan*

That is, while there is value in the items on the right, we value the items on the left more." [agilemanifesto.org 2006]

Figure 6-2 Manifesto for Agile Software Development

These aims give rise to a number of methods which have the following characteristics.

- Agile methods develop software in small iterations, which have development timescale in the order of weeks.
- Each iteration is a miniature software project of its own, and may include all the tasks necessary to release the mini-increment of new functionality: planning, requirements analysis, design, coding, testing, and documentation.
- Agile methods emphasize real-time communication, preferably face-to-face, over written documents. Change negotiations are conducted informally face-to-face between stakeholders.
- Agile development teams are co-located and include all the people necessary to finish the software. At a minimum, this includes programmers and their "customers".

Boehm and Turner [Boehm and Turner 2004] characterised Agile methods as being at the opposite end of a spectrum from "plan-driven" or "disciplined" methodologies. This definition can be misleading, as it implies that agile methods are "unplanned" or "undisciplined" which they are not. Boehm and Turner suggested that development methods exist on a continuum (Figure 6-3) from "adaptive" to "predictive".

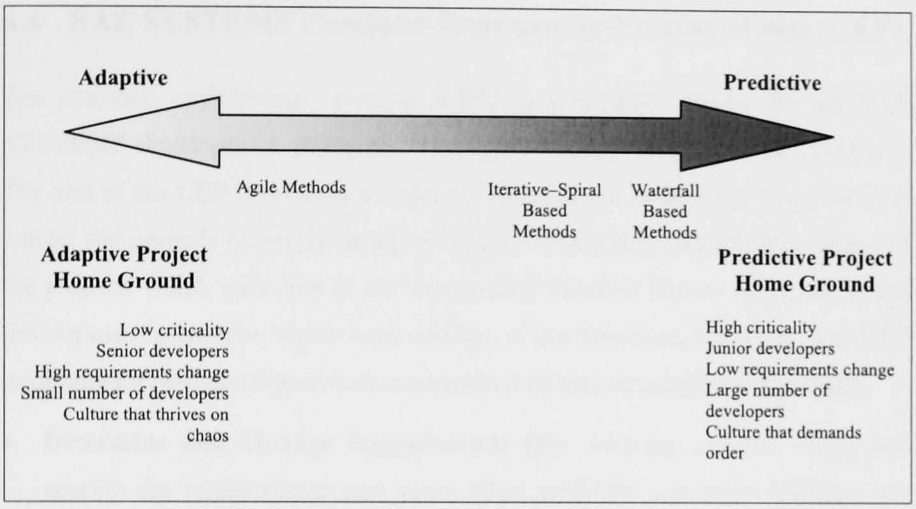

Adaptive
Predictive
Agile Methods
Iterative–Spiral Based Methods
Waterfall Based Methods
Adaptive Project Home Ground
Predictive Project Home Ground
Low criticality
Senior developers
High requirements change
Small number of developers
Culture that thrives on chaos
High criticality
Junior developers
Low requirements change
Large number of developers
Culture that demands order

Figure 6-3 Development Method Continuum

Adaptive development methods adapt quickly to changing project requirements. Therefore, an adaptive team will have difficulty in defining a project plan. In contrast, Predictive development methods define all stages of product development in advance. A predictive team can report exactly what features and tasks are planned for the entire length of the development process. Boehm and Turner [Boehm and Turner 2004], suggest that risk analysis be used to choose between adaptive ("agile") and predictive ("plan-driven") methods. Boehm and Turner suggest that each side of the continuum has its own home ground (Figure 6-3). In summary, agile development methods embrace change though it is not clear on what grounds changes are determined.

With respect to change negotiation, it can be argued that the common use of the "Project Change Board" in the predictive development methods was one of the driving forces behind the Agile movement. The use of the Project Change Boards removes the decision making from the local development process team. This demonstrated in the one of the characteristics of an Agile process, that all negotiations are conducted informally, face-to-face, between stakeholders.

6.4 BAE SYSTEMS Common Engineering Process Model (CEP)

The common engineering process (CEP) is a template model for all BAE SYSTEMS development processes. The CEP owes its origins to the V-Model. The aim of the CEP is to bring a degree of consistency in development processes among the projects currently being developed within BAE SYSTEMS. Many of the projects which took part in the Traceability Practice Survey (Chapter 3) had development processes which were similar, if not based on, the CEP. The CEP development process (Figure 6-4) is composed of nine development processes.

- **Determine and Manage Requirements (R):** Analyse, explore, refine and specify the requirements and agree them with the customer. Manage any change to the requirements. Specify the criteria for customer acceptance of the system and agree them with customer.
- **Perform Functional/Behavioural Analysis (F):** Analyse the required system functions and behaviour to resolve them down to progressively lower level functions and behaviour. Create and agree a behaviour structure that describes system behaviour, sequence and data flows. Repeat this process for each candidate solution produced in process (C).
- **Create Candidate Solution Concepts (C):** Create, assess, refine and describe a number of candidate solution concepts. Establish the feasibility of meeting the requirements and select the preferred options for subsequent specification and design.
- **Design and Specify Sub Systems (D):** Design the system, using the chosen solution as a starting point. Establish the design configuration, partition the system into sub-systems, allocate budgets and define interfaces. Progressively assess and improve the design using feedback from reviews, analysis, specialists, tests and trials. Specify and agree the system design and produce

drawings. Specify requirements for each sub-system. Specify and agree the requirements for test, proving and integration processes and the requirements for test and support equipment. Demonstrate requirements traceability.

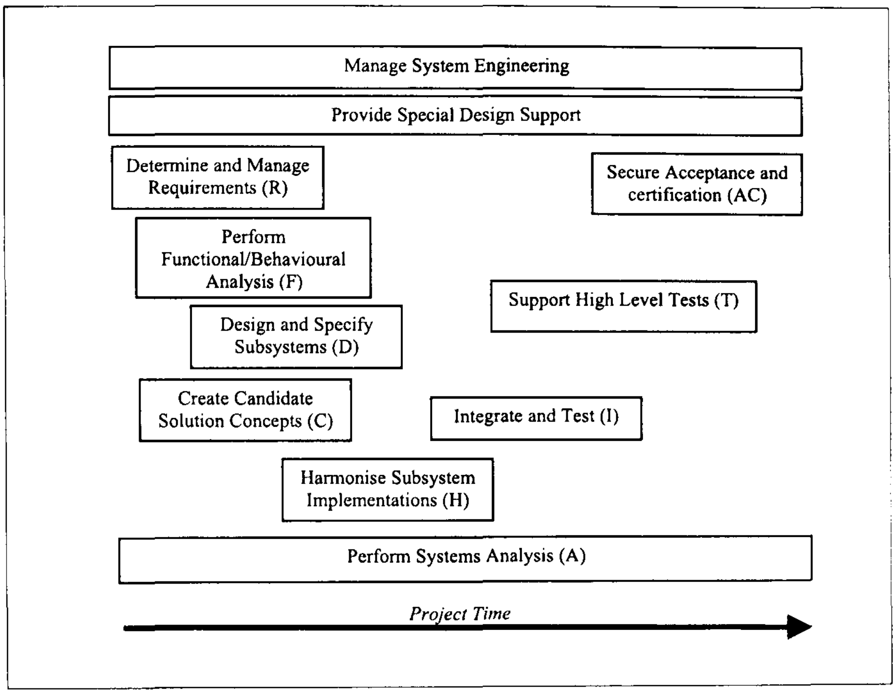

Manage System Engineering
Provide Special Design Support
Determine and Manage Requirements (R)
Secure Acceptance and certification (AC)
Perform Functional/Behavioural Analysis (F)
Support High Level Tests (T)
Design and Specify Subsystems (D)
Create Candidate Solution Concepts (C)
Integrate and Test (I)
Harmonise Subsystem Implementations (H)
Perform Systems Analysis (A)
Project Time

Figure 6-4 CEP Development Processes

- **Perform Systems Analysis (A):** Create models and simulations of the system in its operational environment. Carry out analysis using these models and simulations in order to predict systems properties and behaviour, including predictions of the emergent properties and of system performance within constraints. Use the analysis and predictions to support the development process.
- **Harmonise Sub System Implementation (H):** Assess the emerging sub-system engineering implementations and gather engineering data. Identify any concerns with the implementations and propose solutions. Make recommendations on the acceptability of any design changes and on their

points of embodiment to maintain harmony and compatibility between the developing parts.

- **Integrate and Test System (I):** Produce an integrated strategy early in the lifecycle. Supervise the practical assembly integration and test of prototype system, resolve any technical problems arising and carry out design proving tests.
- **Support Higher level Tests (T):** Plan and support test of the prototype system functioning in its operational environment, with its associated systems, in accordance with a previously defined test strategy. The higher level tests are usually carried out in conjunction with the customer, with the objective of showing that the design meets performance and other requirements when used under realistic operational conditions. The test results are analysed to provide design feedback and obtain evidence to validate the design and lead to customer acceptance.
- **Secure Acceptance and Certification (AC):** Progressively gather and present design proving evidence that the system is compliant with requirements, and secure customer acceptance and certification of the design.

For each development process there is a detailed process description which defines: the activities which the process is composed of, the roles and responsibilities of engineers performing the process, inputs required by the process, outputs produced by the process, process entry and exit criteria. Though CEP is an iterative process, all of the detailed process descriptions are written as if the product will be completed in a single iteration (e.g. similar to a waterfall process). There is no process for producing plans for the next iteration as would be found in the Spiral model based process.

The CEP is vague on the subject of inter-process communications. The CEP says little on the subject other than by defining what information shall be passed between processes. The CEP simply states that inputs to a process should be reviewed and it is not clear how issues arising from these reviews should be resolved.

The detailed process descriptions do not state how changes, due to development iterations or reviews, are to be negotiated. The CEP simply gives precedence to the preceding processes with respect to change. This can cause conflicts, in particular for the Design and Specify (D) process which has two proceeding processes. With respect to the resolution of change issues, the CEP does however describe a project management structure that has the responsibility for escalating issues to the project management team.

6.5 Observations and Summary

The problem of determining the correct baseline to allow development progress to next phase occurs in all predictive development models. Change is inevitable. The predictive models have an inherent bias towards upstream development phases which often results in one-way communication [Al-Rawas and Easterbrook 1996;Curtis, Krasner and Iscoe 1988]. This bias and the need to introduce changes to a baseline often give rise to "throwing the problem over the wall". Boehm observed similar problems and this led him to suggest the WinWin extension to his spiral model to improve negotiations between stakeholders.

It can be argued that the agile software development movement has arisen partly due to the bad or lack of communication found in predictive models. The agile community has tackled this problem by discarding development phases and developing co-located teams able to tackle all aspects of the development. However, within an agile development team there still will be conflict due to team members taking different positions on changes. In such cases, agile team members will have to negotiate these changes and will need to adopt similar objective criteria as described in WinWin.

These observations suggest that, for a development process which is based on a predictive model, a protocol is required that defines how related development teams communicate and negotiate change. This protocol should curtail the upstream bias of these models by allowing the downstream development phases an opportunity to negotiate any changes. Successful change negotiations require, as Boehm observed, objective criteria to base the decision on. One such criterion is the determination of the impact of a change on the existing product. This is how the Automotive Sensor (Chapter 5 – Section 5.4.1) team employed their traceability data in the negotiation of changes to their products.

The next chapter introduces the Traceable Development Contract (TDC). The TDC is proposed as a means of controlling the upstream team bias with respect to the imposition of changes, by employing a inter-team development protocol and traceability to negotiate change.

Chapter 7 Traceable Development Contract

7.1 Introduction

Chapter 6 highlighted the weaknesses in predictive development models with respect to establishing development phase baselines and the inherent bias these models have towards upstream development phases making changes to their baseline. Chapter 5 described how the automotive sensor project employed a traceability system to help the development engineers negotiate customer changes to their baseline requirements. This chapter combines these themes and introduces the Traceable Development Contract (TDC). The TDC is proposed as a means of controlling the upstream team bias with respect to the imposition of changes, by employing traceability to provide a basis for the negotiation of change. By employing traceability in this way, it becomes beneficial to the development engineers and therefore overcomes the Traceability Benefit Problem.

7.2 Origins of the Traceable Development Contract (TDC)

The TDC is based on the traceability practice survey (Chapter 3) and the automotive sensor (Chapter 5) development process and traceability system. The automotive sensor development process is based around a customer–developer relationship. In this relationship, both parties have well-defined roles and responsibilities. For example, the customer is required to produce a specification that is of sufficient quality to enable the development of the product. The customer understands that an incomplete specification that requires frequent updating may result in delays and increased costs. The developer has the responsibility of understanding the specification and resolving any issues with the customer. The developer is also required to demonstrate that the product satisfies the customer's specification. These roles and responsibilities are defined in the purchase contract. The traceability system helps both parties adhere to their respective responsibilities by providing information that helps them negotiate changes to the specification or to the sensor.

In contrast to the automotive sensor project, the rest of the surveyed projects in Chapter 3 were large projects that were developed according to a predictive development model which was the same or similar to the BAE SYSTEMS Common Engineering Process (CEP – see section 6.4). In such a development process, the main "customer" relationship is between a development team and the project management and not between the related development teams. In the BAE SYSTEMS Common Engineering Process (CEP) each development phase/team is a separate entity, consuming inputs, performing development tasks and producing internally validated output. As a result, team managers concentrate solely on the progress of their phase and do not consider the impact of their decisions on their immediate down stream phases.

The weakness of predictive based development processes in establishing baselines and the insular nature of development team management often results in the "throwing the problem over the wall". This was observed during the survey and has also been observed in other multi team development processes by Al-Rawas and Easterbrook [Al-Rawas and Easterbrook 1996] Curtis et al. [Curtis et al. 1988] and Christie et al. [Christie et al. 1996].

The above observations suggest that the establishment of a customer-developer relationship between related development phases would help to alleviate the issues related to the establishment and maintenance of a baseline. This relationship would require an upstream development phase to communicate and negotiate changes to their baseline with the affected downstream phases. This relationship has an additional benefit as the developers who produce a baseline, who will act as customer, have the product knowledge to allow them to validate the suitability of the products produced by the downstream phase.

The automotive sensor project provides a good model on which to base such a customer-developer relationship. As demonstrated, a Traceability system is central to such a relationship as it provides information that allows the negotiation of changes to a baseline and provides evidence for the suitability of the product. As the recording of the traceability relationships would be beneficial to both sets of engineers, such an arrangement would also work towards overcoming the Traceability Benefit Problem.

7.3 An Overview of the Traceable Development Contract

The TDC formalises the interaction of the teams by defining their behaviour with respect to the state of their shared development artefacts. Traceability is employed as a means of assessing the impact of a change to development artefacts and providing a basis for the negotiation of the change. The TDC affords the engineers in the downstream team an element of control over their development environment by limiting the imposition of changes by the upstream team. The TDC introduces a new contractual relationship between cooperating development phases. By keeping the definition of the TDC simple and generic the contract can be applied to each development interfaces (Figure 7-1).

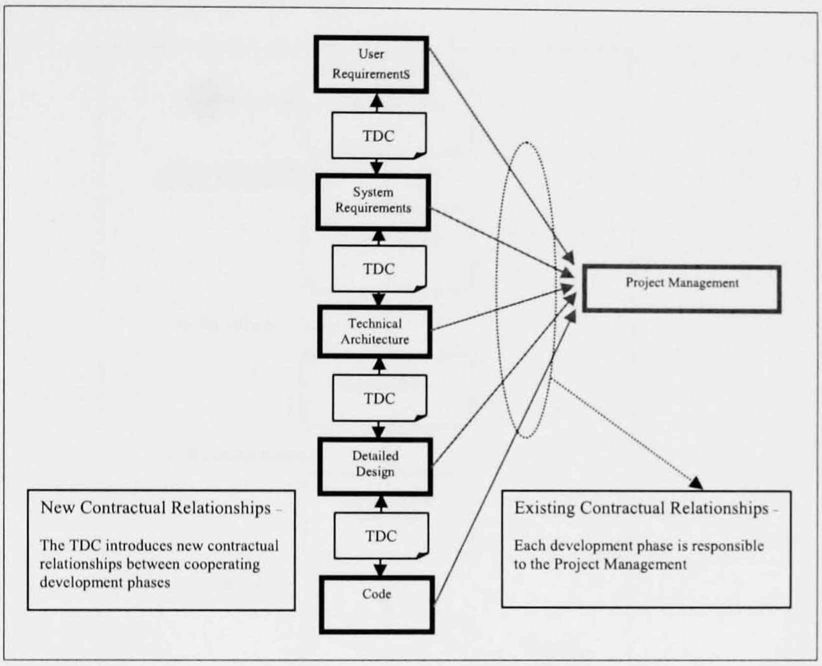

User RequirementS
TDC
System Requirements
TDC
Technical Architecture
TDC
Detailed Design
TDC
Code
Project Management
New Contractual Relationships -
The TDC introduces new contractual relationships between cooperating development phases
Existing Contractual Relationships -
Each development phase is responsible to the Project Management

Figure 7-1 TDC applied to each development interface

The TDC consists of three parts:

1. A protocol that defines the responsibilities and behaviour of each development phase with respect to the establishment and maintenance of the contract
2. Problem artefacts (documentation, diagrams, models etc.) that describe a problem domain (or development baseline).
3. Traceability data structures that record the relationship between the problem artefacts and the solution. The traceability structures provide information that assists in solution development, problem change negotiations and the demonstration of solution validity and completion.

The contract protocol is a means of defining the behaviour of the development teams. The protocol is defined by five stages: Contract Initiation, Problem Discourse, Propose Solution, Development & Refinement and Completion (Figure 7-2). These stages are based on the observations made during the survey and the operation of the automotive sensor team.

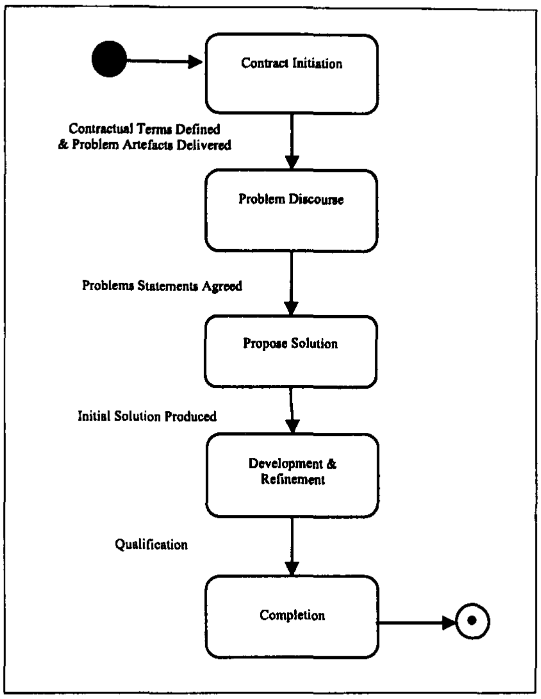

Contract Initiation
Contractual Terms Defined & Problem Artefacts Delivered
Problem Discourse
Problems Statements Agreed
Propose Solution
Initial Solution Produced
Development & Refinement
Qualification
Completion

Figure 7-2 Overview of TDC Stages: UML State Diagram

7.4 Contract Initiation

The Contract Initiation stage is concerned with defining the contractual terms of the work that is to be undertaken. The information that is required to be recorded and agreed at this stage of the contract will be:

1. A description of the activity to be undertaken by the downstream team.
2. The identification of the upstream and downstream stakeholders.

3. A description of the problem artefacts.

4. Planning information: the agreement of dates for the delivery of the problem artefacts and estimated start dates for each phase of the TDC.

5. The establishment of a conflict arbitration procedure and arbitrator.

For development processes that are compliant to development standards such as BS TickIT 2000 [TickIT 2000] and ISO 9003[ISO 2007] contractual items 1 to 4 are required to be defined in the project plan.

Conflict is likely to occur between teams that have a relationship due to problems in the coordination of their activities [Easterbrook 1993]. Therefore, a method of resolving conflict, item 5, is required to be defined and agreed. A suitable candidate for an arbitrator would be the "traditional" chief engineer: an engineer who has technical knowledge yet is separate from the project hierarchy. The Initiation stage lays the foundations for the following stages of the TDC.

7.5 Problem Discourse

The Problem Discourse stage commences once the contractual terms have been agreed in the Contract Initiation stage and the problem artefacts have been made available to the downstream team. The Problem Discourse stage aims to clarify any issues with the problem artefacts and to obtain the agreement of the downstream developer team that the artefacts are suitable for the production of an initial solution. It is the responsibility of the downstream team to review the problem artefacts with reference to their suitability for the production of an initial solution and to agree the status with the upstream development team. The review of the problem artefacts by the downstream team may result in requests for clarification or requests to change problem statements.

Conflict between the teams may occur at this stage and it is the role of the Arbitrator, who was identified in the previous stage, to resolve such disputes. The Arbitrator can reject, accept or defer a change to a later release. Once all the problem artefacts have been agreed upon by the downstream team, the artefacts are frozen to allow for the development of the initial solution. The Arbitrator will be required to take into account the acceptance of the suitability of problem artefacts by the downstream team in the case of future disputes. The Problem Discourse stage is summarised in Figure 7-3.

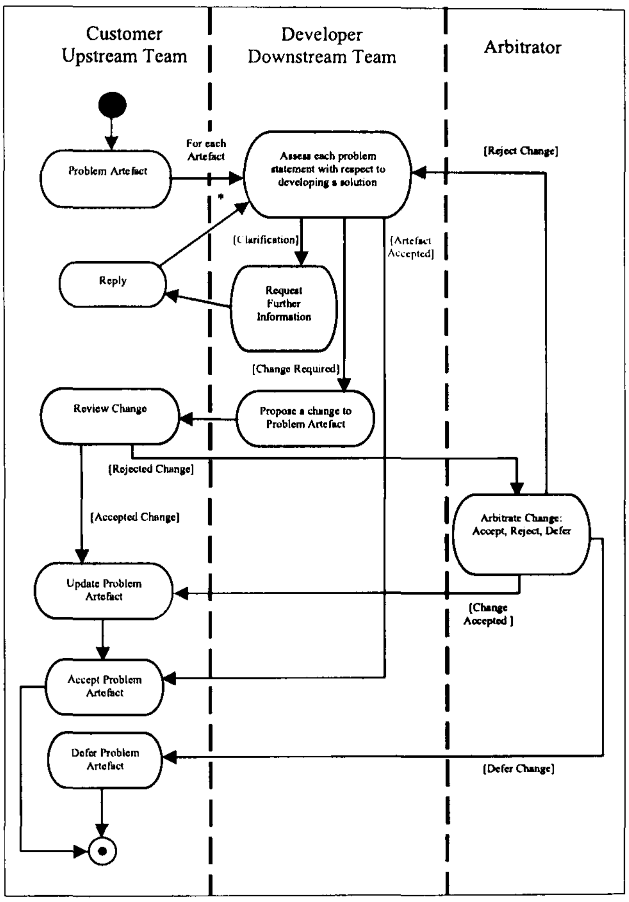


Figure 7-3 Problem Discourse: UML Activity Diagram

7.6 Proposed Solution

The proposed solution stage commences once all problem artefacts have been agreed to be suitable for the production of an initial solution by the downstream team. The aim of this stage is to couple the solution, via traceability relationships (Figure 7-4), to the problem artefacts and to gain agreement from the upstream team of the suitability of the solution. The stage is intended to be of a short duration. It is understood by both teams that the initial solution will be incomplete and will be a *prototype* that will require further development.

This coupling of the problem with the solution provides the downstream team shared control over the problem/solution space as changes to the problem artefacts cannot occur without a solution impact analysis and resulting change negotiation. It is the traceability relationships that provide a means of determining the impact of a change.

The downstream team will be required to record Problem/Solution Satisfaction Traceability to demonstrate what parts of the solution satisfy or address which problem artefacts (Figure 7-4). To determine the impact of a change to the problem artefacts the downstream team will be required to record Solution Decomposition Traceability. To demonstrate to the upstream team that solution is comprehensive and can be validated, the downstream team will be required to record Problem/Test Satisfaction Traceability (Figure 7-4).

For example, the automotive sensor project employed the DOORS tool to manipulate traceability information to produce reports that documented which part of the sensor software satisfied which requirements and how the software would be tested. These reports were used to demonstrate to the customer the suitability of the sensor software.

The presence of problem-solution traceability relationships from previous development iterations will allow the downstream engineers to determine quickly what changes are required for the new solution. This use of traceability relationships to determine component reuse was demonstrated by the automotive sensor project.

Once the downstream team has recorded the traceability relationships between their initial solution and the problem artefacts and demonstrated to the upstream team the suitability of the solution, the contract progresses to the Development and Refinement stage.

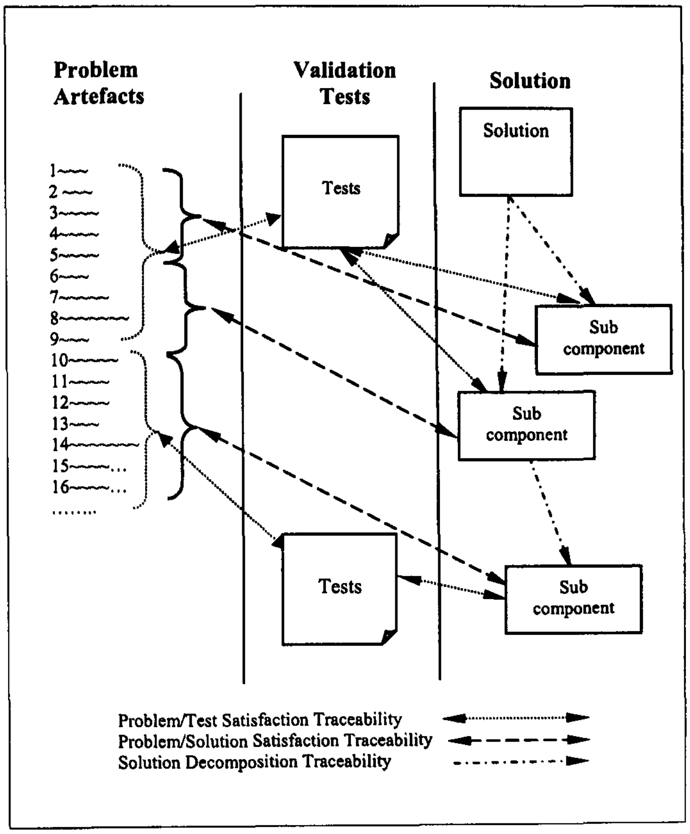


Figure 7-4 Problem Solution Traceability

7.7 Development & Refinement

Once the Proposed Solution stage has been completed, the downstream engineers will continue to progress with the development and refine their solution. As the solution is developed, the downstream team will continue to create new traceability relationships between the problem artefacts and the solution.

During development, it is unreasonable to expect that no changes to the problem artefacts will occur. Change will occur due to the inherent problem of establishing a baseline found in predictive base development processes. The observations made in the course of this thesis suggest that the development issue with respect to baseline change is not that it occurs, but the determination of the impact of changes. It is difficult for development processes that do not record traceability between the problem artefacts and the solution to determine the impact of a change. Without this information, it is difficult for the teams to negotiate the scope of a change. This was observed in the traceability practice survey for development processes, which did not record any traceability information. In such development processes, changes were more likely to be imposed regardless of the impact.

In the Development & Refinement stage, both teams are free to make requests to change the problem description artefacts. The impact of a change to the problem description artefacts is determined from the traceability relationships. Based on this information, the change is negotiated with consideration given to development timescales as defined in the contract initiation stage. Conflict may occur between the teams during the negotiation of a change. It is the Arbitrator's role to resolve such conflicts in a similar manner to the arbitration of change requests in the Problem Discourse stage.

The Development & Refinement stage continues until the downstream team can demonstrate to the upstream team that the solution addresses all the problem artefacts, or the allocated development time as defined in the TDC has expired.

7.8 Completion

Projects are rarely fully completed [Weinberg 1998] and this is demonstrated in the Automotive Sensor Case study where approximately 2% of the customer requirements remained unsatisfied on completion of the project. The aim of the Completion stage is to demonstrate what has been successfully completed.

It is the responsibility of the downstream team to demonstrate to the upstream team that the solution addresses the problem and that this can be demonstrated by validation tests and recorded results. The upstream team has the responsibility of accepting (or not) the evidence of completion and confirming the completion of the contract. In the automotive sensor case study (chapter 5) reports were generated from the traceability relationships to demonstrate to the customer that the sensor software satisfied their requirements and that it had been verified by testing.

In the case where the solution has not completely addressed the problem it is the responsibility of the downstream team to list the areas in which the solution is deficient. Again, this information is obtained from the traceability relationships. If this occurs both teams will be required to negotiate the suitability of the solution and this may result in the issuing of a new TDC. These negotiations may result in conflict and the Arbitrator may be called upon by either team to make a judgement on the suitability of the solution based on the traceability information.

As demonstrated in the automotive sensor case study (chapter 5) the problem/solution traceability data becomes a valuable resource for further development, for it allows the determination of which components can be reused in product variants or in future development iterations.

7.9 Addressing Criticisms

The TDC can be criticised as another form of bureaucracy that will burden hard-pressed engineers further. This criticism can be countered as follows. The TDC gives a structure to the interaction of related development teams. It was demonstrated in Chapter 6 that development processes based on a predictive development model, such as BAE SYSTEMS CEP, often do not define how related teams should cooperate. The TDC also gives a development context to the recording of traceability data. The TDC describes how the traceability data is employed to benefit the development process for example, in change impact negotiations. The traceability surveys (Chapter 3) demonstrated how a perceived lack of purpose for the recording of traceability data resulted in the poor recording and maintenance of traceability data. The TDC creates a customer-developer relationship between development phases allowing the exploitation of the upstream team's expertise. This is in contrast to present predictive development processes where the main contractual relationship is between a team and the project management. However, the question of whether the TDC adds bureaucracy to the development process will only be answered by the implementation of the TDC in a live development environment, which is discussed in Chapter 10.

7.10 Summary

The TDC addresses the problem of controlling the upstream team bias with respect to the imposition of changes to a baseline by employing traceability to provide a basis for communication and the negotiation of change. By employing traceability in this way, it becomes beneficial to the development engineers and therefore overcomes the Traceability Benefit Problem. The benefits of the TDC are further illustrated in Chapter 9 (An Illustration of the TDC) which describes how the contract would be employed in development of a hypothetical jet trainer. By making the TDC applicable to each development phase interface progress towards the elusive goal of end-to-end traceability can be achieved. The next chapter will examine what data structures are required to achieve the aims of the TDC.

Chapter 8 TDC Traceability Data Structures

8.1 Introduction

Chapter 7 outlined the Traceable Development Contract (TDC) and how it employs traceability as a basis for negotiating changes to a development baseline. This chapter examines the data structures required to achieve the aims of the TDC. A number of guiding principles have arisen out of the development of this thesis, which has influenced the design of TDC Traceability data structures.

- The structures must be generic and applicable to all development phase boundaries.
- The structures must only record information that is relevant to the TDC and therefore be able to record information that :
    - Demonstrates Problem-Solution satisfaction information
    - Allows the navigation of the solution
    - Demonstrates solution validation

- Supports stakeholder communications.

This chapter describes the traceability data structures that achieve the above principles and how the development of the structures has been influenced by previous traceability structures and the Traceability Practice Survey. The chapter concludes by examining how the TDC traceability data structures can be exploited further to provide solution maturity and design metrics.

8.2 Influences of Existing Traceability Structures

A number of traceability structures have been proposed that have similar guiding principles to that of the TDC Traceability data structures. The traceability structures which have influenced the development of the TDC traceability data structures are Rich Traceability [Dick 2002], Contribution Structures [Gotel 1995] and Design Rationale Capture System (DRCS) Language [Klein 1993].

8.2.1 Problem-Solution Satisfaction Traceability

Satisfaction traceability is the recording of a relationship between a solution artefact and problem artefact (Figure 8-1) where the solution artefact satisfies, either fully or partially, the demands of the problem artefact.

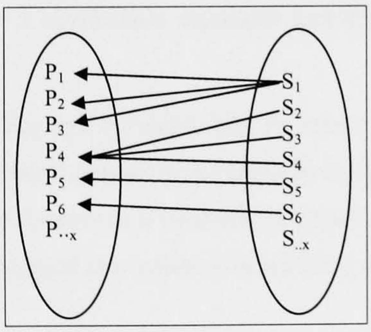


Figure 8-1 Simple Solution Satisfaction Traceability

Satisfaction traceability relationships can be captured in the form of a traceability matrix or in a hyperlink based tool such as DOORS [DOORS 2007]. These relationships are of limited use to the engineer, as the presence of a relationship does not inform the engineer if the solution artefact satisfies the problem artefact partially, totally or is a part of a collection of artefacts that combine to satisfy the problem artefact. As a result, the engineer may have difficulty in determining the impact of a change by just following the satisfaction relationships.

To address these problems, additional domain information is appended to the satisfaction relationship to allow the engineer to determine the contribution the artefact makes to the solution (Figure 8-2). This information is referred to as a satisfaction argument, though it goes by many different names dependant on the development phase, for example:

- "Requirements Elaboration" for a satisfaction argument that demonstrates how the system requirements are derived from the user/system specification.
- "Design Justification" for a satisfaction argument that demonstrates how the design is derived from the requirements.
- "Implementation Strategy" for a satisfaction argument that demonstrates how the code is derived from the design.
- "Test Strategy" for a satisfaction argument that demonstrates how the tests exercise the code.

In essence, the above data has the same aim, to present an argument to provide evidence of how the solution artefact contributes to satisfying the demands of the problem artefact. This information is normally recorded as plain text, though data structures have been advanced as a means of describing a satisfaction argument.

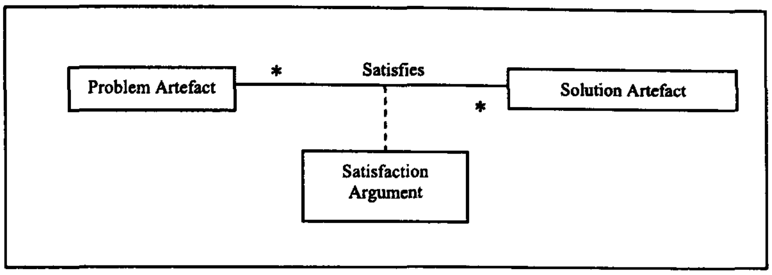


Figure 8-2 A Simplified UML Class Diagram of a Satisfaction Relationship

Rich Traceability [Dick 2002] is promoted as a means of providing evidence of the contribution that a solution artefact makes to the satisfaction of a problem artefact by recording a satisfaction argument. In Rich Traceability, the satisfaction relationship is appended with a satisfaction argument expressed in plain text. Propositional operators are employed to indicate the way solution artefacts combine to satisfy a problem artefact:

- By conjunction (&) indicating that, the contribution of all the solution artefacts is necessary for the satisfaction of the problem artefact to hold. (Figure 8-3)
- By disjunction (OR) indicating that the contribution of any one of the solution artefacts is necessary for the satisfaction of the problem artefact to hold. (Figure 8-3)

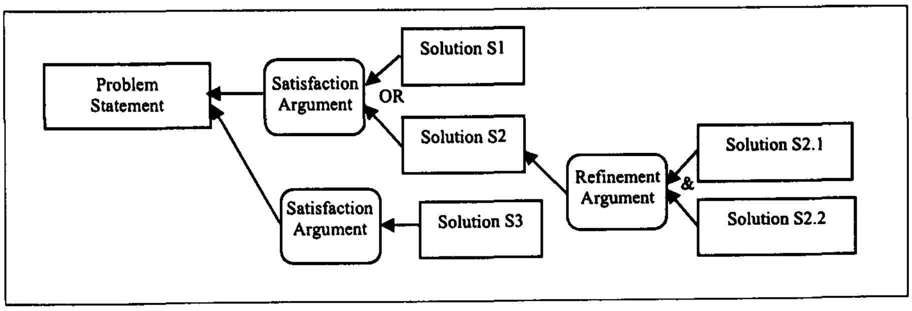


Figure 8-3 Refinement of Solution and Satisfaction Arguments

Rich Traceability allows the engineer to refine his solution by use of refinement satisfaction arguments. Rich Traceability was successfully employed by Praxis, for Railtrack in the development of requirements for West Cost Rail Route modernisation project. Praxis has incorporated extended Rich Traceability into their REVEAL requirements engineering method [Praxis 2007].

Rich Traceability can be thought of as a member of the collection of Goal-Oriented Requirements Engineering (GORE) methods that also include Goal Structuring Notation (GSN) [Kelly 1999], Knowledge Acquisition in autOmated Specification (KAOS) [Darimont et al. 1998] and Goal-Based Requirements Analysis Method (GBRAM) [Anton 1997]. These methods have similar taxonomies that consist of a network of goals, which are connected by links. Each method has its own taxonomy of goals but in essence there are two broad classes of goals: goals that define the desired characteristic or state of the system and goals that define how a system characteristic or state will be achieved. Goal links describe how a sub-goal is related, either positively or negatively, to its parent goal. Goal links can be combined with combinational operators such as AND/OR.

An alternative to these GORE methods is Problem Frames [Jackson 2001]. Problem Frames represent the problem as collections of sub-problems, each of which is smaller and simpler than the original. A problem frame defines the shape of a problem by capturing the characteristics and interconnections of the parts of the world it is concerned with. This technique employs problem diagrams to describe the relationships between the machine, the problem domains and the requirements. A problem diagram (Figure 8-4) shows:

- A dashed oval representing the requirement to bring about certain effects in the problem domains
- Dashed lines representing requirements references
- The Machine that is to be built is represented in bold

- The domain rectangles represent the interactions the machine has with the world

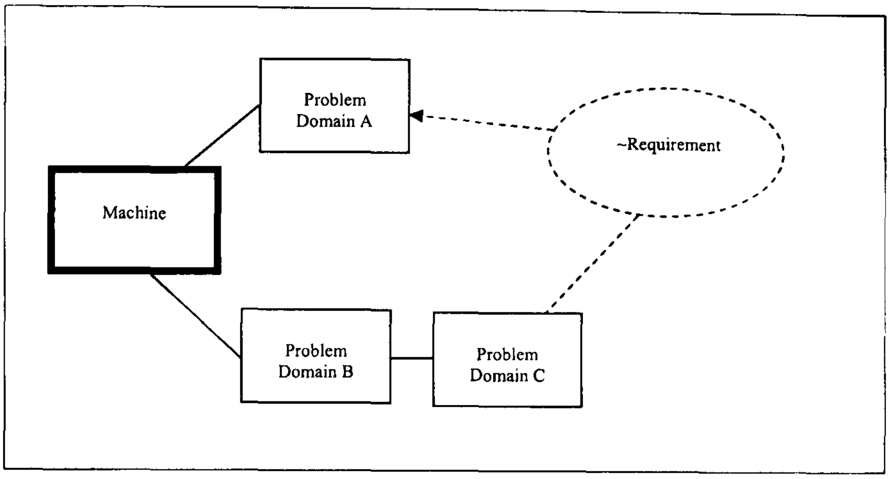


Figure 8-4 A Simple Problem Frame diagram

Hall [Hall et al 2002] demonstrated how problem frames can be employed in the iterative development of an architecture and its requirements

8.2.2 Contribution Structures

Gotel [Gotel 1995] proposed the use of traceability structures, known as Contribution Structures, to improve communications and cooperation between the stakeholders involved in the elicitation of requirements. Contribution Structures record the relationship between contributing stakeholders and an evolving requirement. Contribution structures represent a requirement as an artefact. An artefact can be a document, model or diagram. Artefacts are classified as being primitive or composite, which are constituted from further primitive or composite artefacts. Artefacts are created and maintained by Agents, who are stakeholders involved in the development of a requirement. There are three classes of Agent: a principal (P) who established the artefact, an author (A) who expresses the artefact and a documenter (D) who records or transcribes the artefact. A stakeholder can perform any combination of these agent roles. The principal's responsibility is to determine and set the artefact's state to approved, pending approval or not approved. The author's responsibility is to determine how the artefact is related to other artefacts. The documenter's responsibility is for the physical and presentational aspects of the artefact. Artefacts are related to each other by one of two connecting relationships, referencing and adopting. Adopting relationships represent the following changes to an artefact:

- Copy – use existing information as is with no changes or additions.
- Add – use existing information with extensions to the content
- Remove – use existing information with reduction in content.
- Alter – use exiting information with changes to clarify the content.

Reference relationships provide additional information to improve the interpretation of the artefact. The combination of these relationships results in a structure as shown in Figure 8-5.

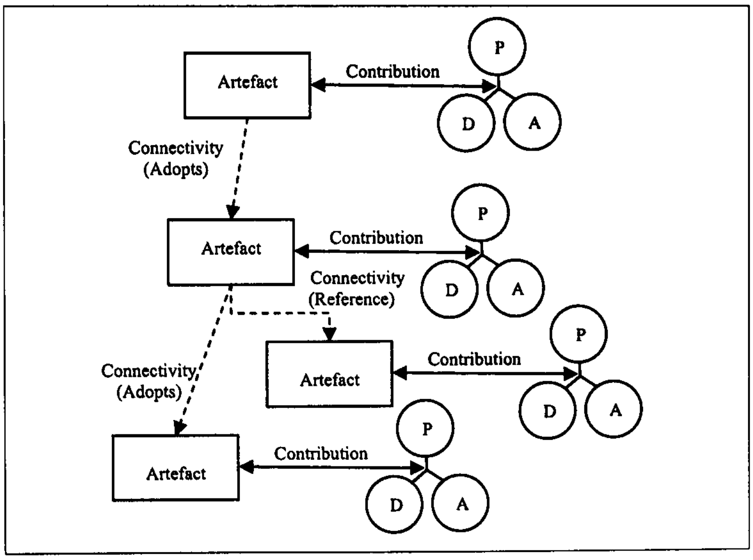


Figure 8-5 Contribution Structure Relationships: Artefact Evolution

8.2.3 Design Rationale Capture System (DRCS) Language.

Klein [Klein 1993] tackled the problem of developing generic data structures, which would capture the rationale for interdependencies between development artefacts. His approach was to consider the interdependencies between developments artefacts to be a result of a number of decisions that are made during the course of a project. The resulting DRCS language consists of a vocabulary of assertions consisting of entities such as modules, tasks, specifications and versions, as well as claims about these entities. The language is divided into two groups of structures, Synthesis and Evaluation. The Synthesis structures, Artefact Synthesis (Figure 8-6 Artefact Synthesis) and Plan Synthesis (Figure 8-7 Plan Synthesis), record the composition of the product and how it relates the production plan.

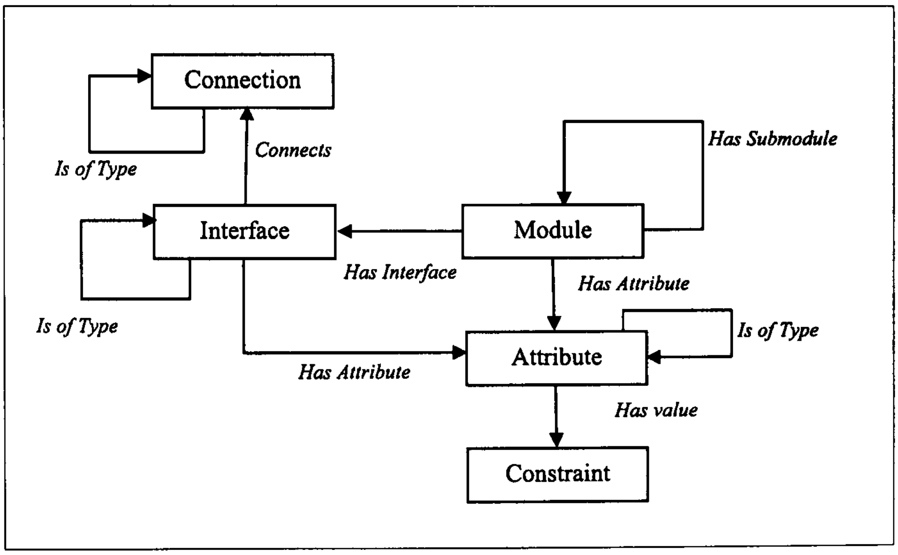


Figure 8-6 Artefact Synthesis

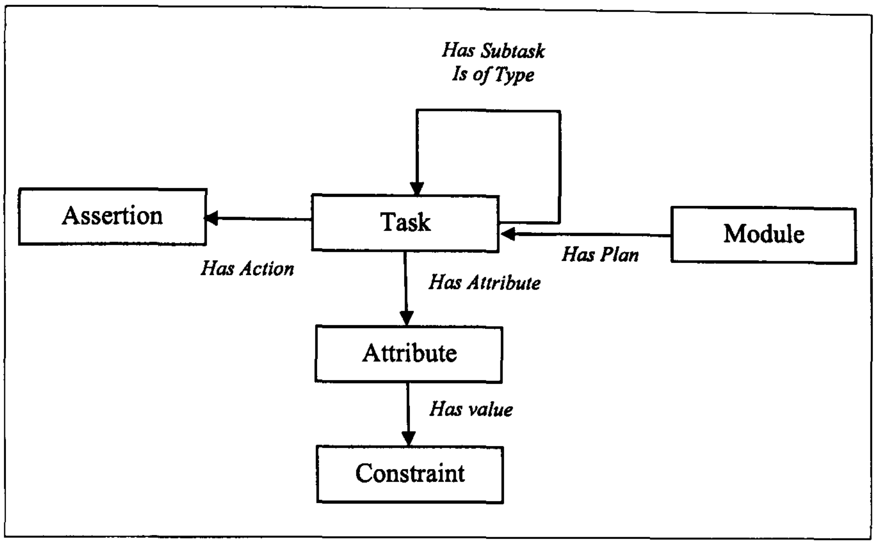
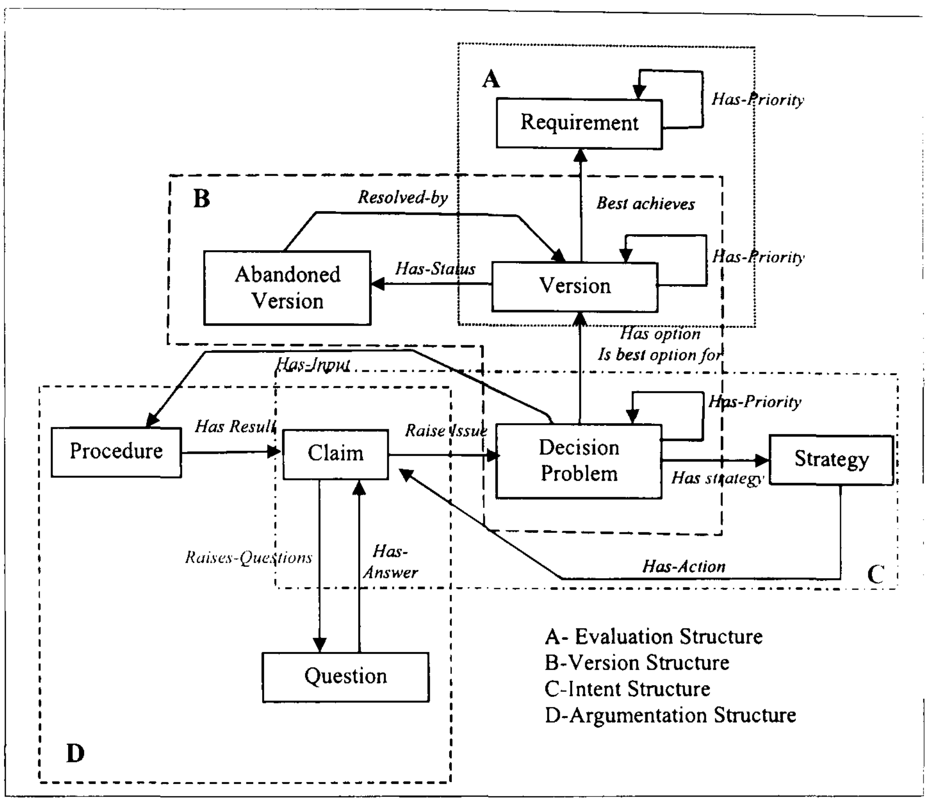


Figure 8-7 Plan Synthesis

The Evaluation group of structures (Figure 8-8) capture the design specifications as well as how well they have been achieved. This group of structures consist of Evaluation, Intent, Versions and Argumentation. The Evaluation structure links the requirement specification to the artefact version that best achieves the requirement. The Version structure captures the relationship between the current artefact version that satisfies the requirements and the previous rejected versions of the artefact. The Intent Structure records decisions made in the choice of the current artefact version. Closely related is the Argument structure that captures the argument for the chosen decision.



A- Evaluation Structure
B-Version Structure
C-Intent Structure
D-Argumentation Structure

Figure 8-8 Evaluation Structures Group

8.3 Influences of Traceability Practice Survey

The Traceability Practice Survey (Chapter 3) raised a number of issues with respect to the recording of traceability data structures. The most common issue raised by the engineers was that a traceability data structure should not require an engineer to duplicate information but should refer to the original source documents.

The survey raised the issue of recording satisfaction arguments. Where a Traceability tool allowed the recording of a satisfaction argument, engineers stated that it was either obvious or often too complex to be transcribed in a few paragraphs and such complex arguments were better described in the project documentation.

For example, the MBDA ASRAAM project (refer to section 3.5.6) took a different approach to the recording of satisfaction arguments. These projects did not try to justify the presence of a traceability relation. They appended the traceability relationships with data which was relevant to the use it would be put to. For example, if the primary aim of recording traceability was for impact analysis, then warnings would be appended to relations indicating the consequences of a change. This targeted additional information proved to be popular with engineers.

The survey also highlighted problems when a set of functional derived requirements was mapped onto an object-oriented design (OOD). Engineers claimed that it was difficult to determine the correct level of mapping, for a requirement may be satisfied by the parent object or by one or more of the inherited objects. The functional requirements to OOD mapping issues were only partly solved by the adoption of a mapping standard that dictated how functionality was related the OO design.

8.4 TDC Traceability Data Structures Design

This section describes how the influences of the previous Traceability data structures and the Traceability survey have resulted in the following generic Traceability data structures, which satisfy the guiding principles set out at the beginning of this chapter.

The key design decision for any traceability structure is whether the structure should record all the product information or act as an indexing system that informs the engineer of the location of the relevant information. There are advantages and disadvantages to both approaches.

8.4.1 Design Decisions

The Automotive Sensor project (Chapter 5) was unique among the surveyed projects as it was the only project which recorded all project information in its traceability system. This approach had a number of advantages. For example, data was not duplicated and there was no need to maintain external references. This enabled up-to-date and consistent project documents to be generated from the project data contained in the traceability system. The main disadvantage of this system was the restricted set of tools that could interface with the DOORS tool.

Researchers have tried to address this problem of data sharing between tools by developing traceability repositories that interface with a wide range of development tools. The AP233 application protocol data model [Herzog 2000] is an example of a data model for such a traceability repository. Another example of a traceability data exchange model is the Meta-Modelling Approach to Traceability for Avionics (MATra) [Mason 1999]. Unfortunately, the success of these data exchange models or repositories have been limited due to complicated data conversion required to support a limited range of development tools.

For the remainder of the surveyed projects their traceability systems contained a mixture of internal data and references to external data and the application required to manipulate this data. Though this approach has the inherent problem of maintaining external references, it does not restrict the use of development tools. As it is not possible to restrict or even to specify the tools required for all developments phases, the TDC traceability structures adopt the approach of recording references to external data sources and the location of the application required to manipulate the data. This approach of referencing is compatible with the developing XML technologies, such as XLink [Xlink 2007], which allow links to be created between diverse range of media artefacts. The XML Linking Language (XLink) allows elements to be inserted into XML documents in order to create and describe links between resources. It uses XML syntax to create structures that can describe the simple unidirectional hyperlinks of today's HTML, as well as links that are more sophisticated. The Xlink standards and related tools are presently under development.

The TDC traceability structures are required to be applicable to all development phases. This requirement gives rise to the idea of a "generic artefact" which can be decomposed as required into further artefacts. The "generic artefact" is the basic building block of the TDC traceability data structures. Problem and Solution Artefacts are generalisations of this common development artefact (Figure 8-9).

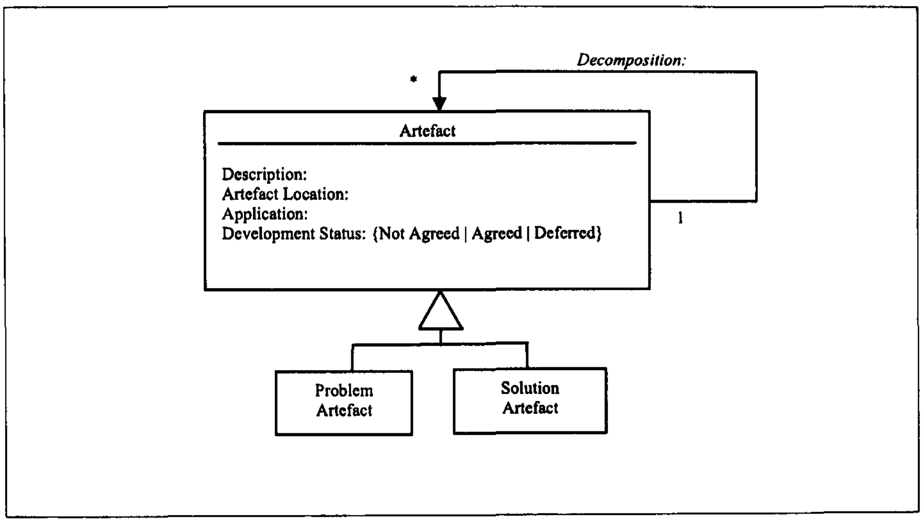


Figure 8-9 Problem & Solution Generalisation of a Common Artefact (UML Class Diagram)

Finally, the previous influences and the original guiding principles (refer to 8.1) have given rise to four basic data structures, Artefact, Artefact Satisfaction, Artefact Decomposition and Artefact Validation.

8.5 Artefact

The aim of the Artefact data structure (Figure 8-10) is to support the Problem Discourse and Development & Refinement stages of the TDC. In the Problem

Discourse stage, the Artefact structure aims to support the clarification of issues with the problem artefacts and to record the agreement of downstream developer team that these artefacts are suitable for the production of an initial solution. This is achieved by recording the queries and related replies raised on each artefact and their agreed development status. The Development Status attribute records the state of agreement between the two teams on the suitability of the artefact for the production of a solution. The artefact can have a Development Status of not agreed, agreed or deferred.

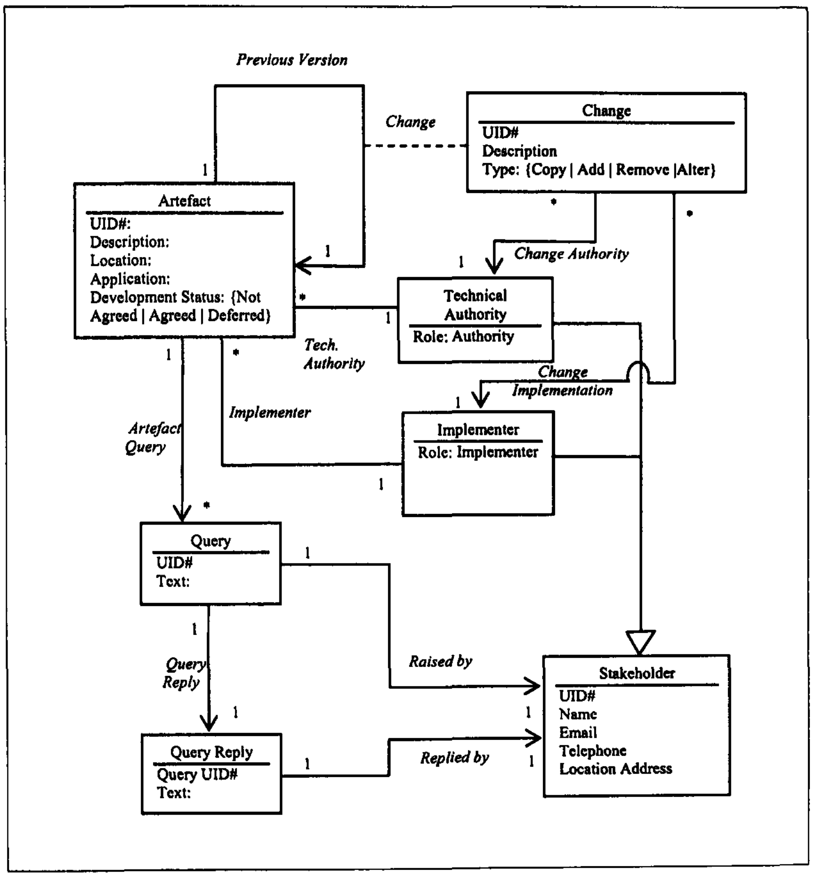


Figure 8-10 Artefact Structure (UML Class Diagram)

In the Development & Refinement stage, the Artefact structure supports the recording of changes to problem or solution artefacts. This information would be recorded by two separate structures, problem artefact changes and solution artefact changes, both of which are instantiations of the generic Artefact structure.

Development artefacts have stakeholders who are interested in the development and maintenance of the artefact. From the survey, there appear to be two classes of stakeholder, the Technical Authority and the Implementer. The Technical Authority is normally an engineer who has the responsibility of overseeing the production, and the approval of the artefact. This stakeholder plays a similar role to that of Gotel's Principal Agent. The Implementer can be a number of engineers who are or have been involved in the production and maintenance of the artefact.

Again, the role of this stakeholder is similar to the combined roles of Author and Documenter Agents proposed by Gotel. The changes that are allowed to be made to an artefact draw upon Gotel's Adopting Relation. A change to an artefact can be a Copy, Add, Remove or Alter just as with Gotel's relation.

8.6 Artefact Satisfaction

The Artefact Satisfaction structure (Figure 8-11) lies at the heart of the TDC and can be thought of as the core traceability structure. The purpose of this structure is to record the relationship between problem and solution artefacts. This information is employed throughout the TDC:

- In the Proposed Solution stage of the TDC to demonstrate the coverage of the initial solution.
- In the Refinement stage of the TDC to determine which solution artefacts are affected by changes to problem artefacts and vice versa.
- In the Completion stage of the TDC to demonstrate the coverage of the final solution and how it will be validated.

As Dick [Dick 2002] stated, the simple recording of problem solution relationships may provide limited information and a satisfaction argument may be required to describe the contribution the solution artefact makes to the satisfaction of the problem. In practice, engineers found the writing of such arguments difficult. Dick suggests that this may be a reflection of the lack of understanding of the underlying relationships. The survey implies that there is a trade-off between the effort expended in writing such an argument and the clarity it brings to the interpretation of the problem-solution relationship. However, for complex or rigorous transformations a satisfaction argument is required and GORE techniques such as Rich Traceability provide a suitable method of describing such an argument. Therefore, the Artefact Satisfaction structure has an associated class, a Satisfaction Argument, which refers to a solution argument describing how the solution contributes to satisfying demands of the problem artefact.

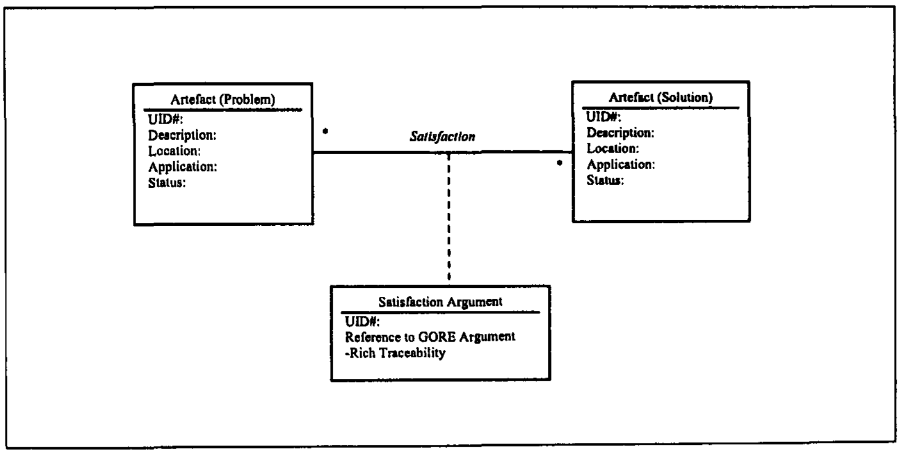


Figure 8-11 Artefact Satisfaction (UML Class Diagram)

The Artefact Satisfaction structure (Figure 8-11) is a many to many relationship, such relationships are often difficult to comprehend. Therefore, the Artefact structure can be thought as a composition of two simpler, one to many, relationships: Satisfaction-Problem View and Satisfaction-Solution View (Figure 8-12.)

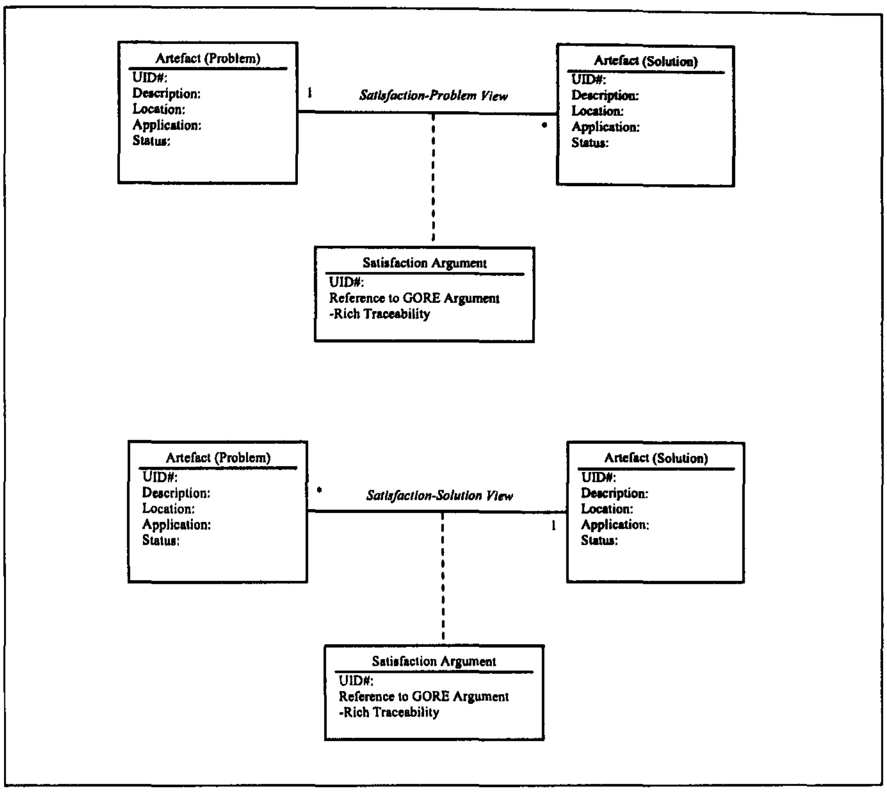


Figure 8-12 Artefact Satisfaction: Problem and Solution Views (UML Class Diagram)

These two relationships represent the view of each team. The upstream team will be mainly concerned with the problem view, while the downstream team will be concerned with the solution view.

8.7 Artefact Decomposition

The aim of the Artefact Decomposition structure (Figure 8-13) is to allow the engineer to describe the compositional relationships between artefacts that combine to form the problem or the solution. The degree of decomposition is a practical issue. Fine granularity gives rise to a large number of artefacts, which in turn results in high data entry and maintenance burdens. The indications, drawing upon the traceability survey (Chapter 3) and the automotive case study (Chapter 5), are that 200-300 artefacts seems to be the maximum number that a small team (of up to 5 people - 50 to 60 objects per person) can handle comfortably.

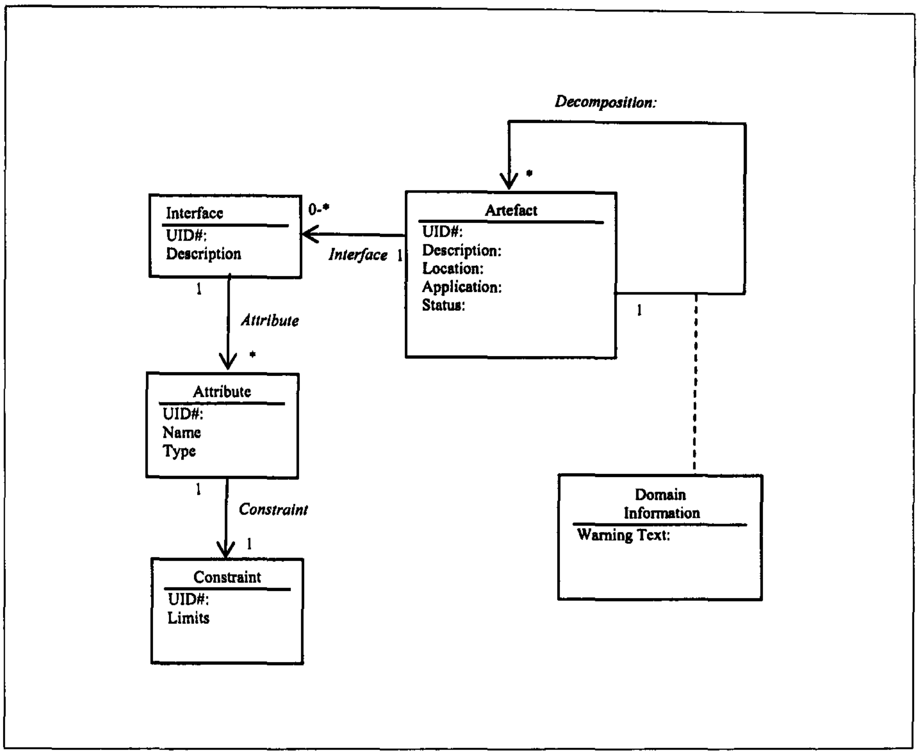


Figure 8-13 Artefact Decomposition (UML Class Diagram)

The Artefact Decomposition structure takes a similar approach to Klein's Artefact Synthesis structure. The method of decomposition, e.g. functional or object orientated is not recorded, only that there is a logical decomposition relationship between artefacts.

The aim of the TDC data structures is to provide information to allow the negotiation of change. Both Klein and the traceability practice survey highlighted the importance of being able to determine the impact of a change on interfaces exhibited by an artefact. Similar to Klein's Artefact Synthesis structure the interfaces exhibited by the artefact are recorded in Artefact Decomposition structure. For each interface, the attributes of the interface and their constraints are also recorded.

Making changes to solution artefacts' relationships may produce unwanted effects. Unwanted effects related to the non-functional aspects of the system, such as memory usage, timing and security are difficult to determine without domain knowledge. The engineers at MBDA tackled this problem by tagging solution artefacts with known non-functional problems with "change warning" notes. These notes were informal warnings aimed at other engineers who may not have an in-depth knowledge of the domain about the problems that may occur if an artefact was changed.

As a result, the Artefact Decomposition structure has an associated class, Domain Information, which will allow the recording of domain information to aid the interpretation of the traceability data.

8.8 Artefact Validation

The Artefact Validation (Figure 8-14) structure records how an artefact will be validated. This structure aims to support the Proposed Solution, Development and Completion stages of the TDC. In these stages, it is the responsibility of the downstream team to be able to demonstrate how they intend to validate their solution.

The approach adopted in the automotive sensor case study (Chapter 5) was the decomposition test descriptions. In this case study test concepts described the testing at a high level. Test concepts were decomposed into test procedures which were in turn decomposed into test case and test steps. Individual test cases and steps were reused across a number of test procedures.

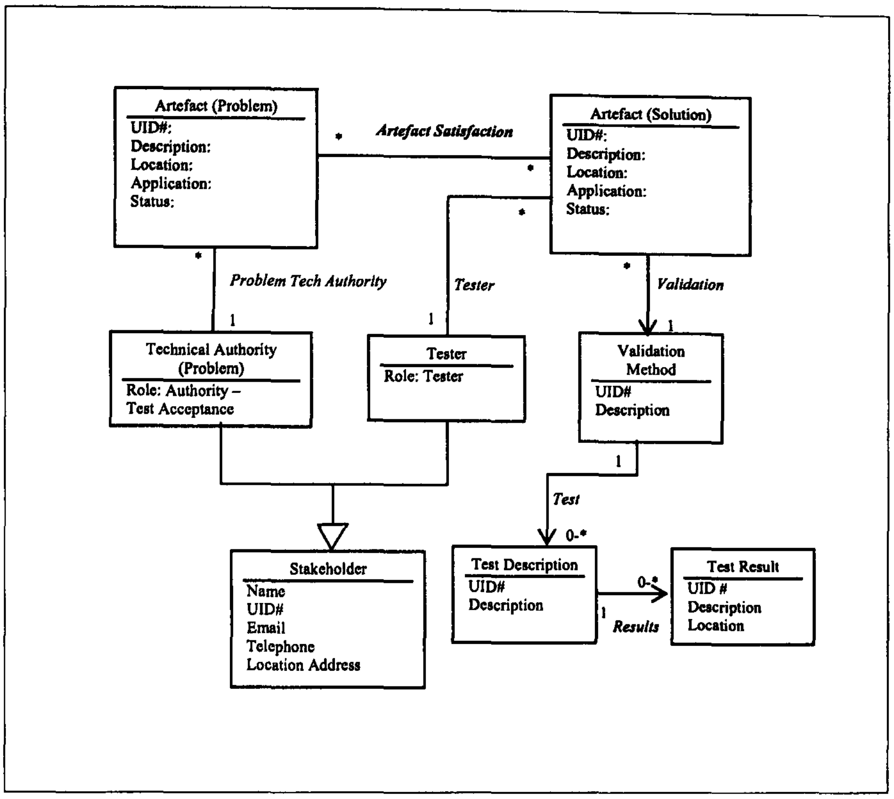


Figure 8-14 Artefact Validation (UML Class Diagram)

The Artefact Validation structure records two levels of test decomposition, a Validation Method that is a high-level description of the required testing and Test Descriptions which define individual tests. Validation Method will address a number of artefacts and Test Descriptions can be reused by a number of Validation Methods.

As the contract progresses to completion, it is the responsibility of the downstream team to demonstrate the solution has been adequately tested. The upstream team has the responsibility of accepting, or not, the validity of the testing. The Artefact Validation structure records the upstream stakeholder who is responsible for accepting the validity of the testing.

8.9 TDC Data Structure Summary

Traceable Development Contract (TDC) data structures are a refinement of existing traceability data structures. The structures have been kept simple and generic so enabling the TDC to be applied across number of development boundaries. These data structures can be considered the basic building blocks that can be extended as the development environment demands. The data structures are similar to structures that are already commonly employed. For example, many of the attributes of the Artefact structure will be found in configuration control data structures. This means that existing tools, such as DOORS, Commercial Relational Data Bases and PVCS, can be employed to implement the contract. Appendix B describes relational schema for an example implementation of the structures.

A criticism that can be made of previous traceability structures is that they lacked a development context: when should the structures be populated, by whom and how should the traceability data be employed in the development process. The Traceable Development Contract protocol (Chapter 7) provides a context to these structures by stating who will populate the structures and how the data will be employed to benefit the local development process. In this way, the TDC protocol brings a purpose to these traceability data structures.

8.10 Summary

Traceable Development Contract (TDC) data structures are a refinement of existing traceability data structures. The structures have been kept simple and generic so enabling the TDC to be applied to any development interface. These structures can be considered the basic building blocks that can be extended as the development environment demands. These simple structures work in conjunction with the TDC stages to provide information that aids the negotiation of change to development baseline artefacts; they also provide additional information on the maturity of the solution.

Having described the data structures and the TDC protocol (Chapter 7), the next chapter illustrates how they could be employed in the development of software for a hypothetical jet trainer.

Chapter 9 An Illustration of the TDC

9.1 Introduction

Chapter 7 outlined the TDC protocol and Chapter 8 described the data structures required to support the contract. This chapter builds upon this work by describing how a contract may work in practice. To illustrate the TDC, and the complexity of the aerospace industry, this chapter will consider the development of the Mission Planning System software for a hypothetical Jet trainer. The illustration is not a proof or a validation of the TDC, it is presented here as a means of exemplifying the ideas presented the previous chapters.

The Mission Planning System is composed of two parts, the aircraft's mission computer and a land-based mission planning system. Each part is specified by a common requirements team, though the software is developed by two different teams. This chapter outlines how the requirements team and software design team, which are developing software for the aircraft, would work according to the TDC and how they would employ the traceability structures. These working practices are compared and contrasted with the relationship the requirements team has with the land-based software development team that employs a traditional method of communications: issuing interface documents and holding review meetings.

9.2 Background: Accipiter 300

The hypothetical Accipiter 300 is the latest of a series of jet trainers produced by the (fictional) British Aircraft Corporation (BAC). This aircraft has a facility that allows the pilot to load a flight-plan into the aircraft's mission computer. In flight, the aircraft's mission computer employs this information in conjunction with information from its positional sensors (Figure 9-1) to overlay mission related information on the pilot's displays.

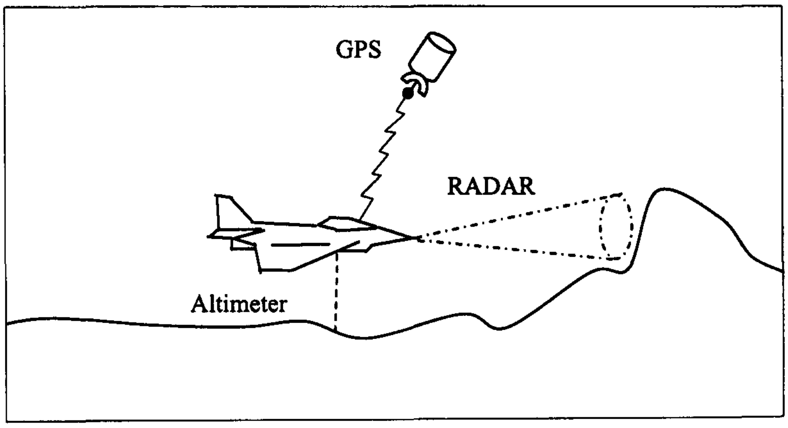


Figure 9-1 Positional Sensors

9.2.1 Mission Planning System

The Mission Planning System for the Accipiter consists of two parts: the aircraft's mission computer and a land-based mission planning system. The land-based mission planning system allows the pilot to create and store his flight-plan in the form of a series of navigational reference points, known as waypoints. The flight-plan is transferred to the aircraft's mission computer via a 4mm tape data cartridge.

The Accipiter's mission computer reads the data cartridge before flight, checks the validity of the data and stores the resulting flight-plan. In flight, the mission computer employs the flight-plan information in conjunction with information from the aircraft's positional sensors to overlay mission related information on the pilot's displays. During flight, the mission computer stores information from the aircraft's positional sensors (Figure 9-1) so that the flight can be recreated on the land-based mission planning system.

9.2.2 Development Organisation

The development of the Mission Planning System is spread across the UK. The elicitation and control of the requirements for the Mission Planning System is performed by the main contractor, BAC, based in the North West of England. The software for the aircraft's mission computer is developed by a subsidiary of BAC based in the South West and the hardware by a subsidiary based in the East of England. The hardware and software for the land-based mission planning system are produced by a separate company, FET Systems, based on the south coast of England.

9.2.3 Scope of Illustration

This illustration will consider how traceability can employed in the development of the aircraft's mission computer. This illustration considers the implementation of an upgrade that occurs after the initial release of the requirements.

The change in functionality is that a Secure Digital (SD) High Capacity (HC) non-volatile memory card will replace tape data cartridges for the transfer of flight data between the aircraft and the land based planning system. The SD card will act as a virtual hard disk and there will be no requirement to validate the data held on the card.

9.2.4 Use of Traceability

The BAC South West software team employs a traceability tool to record the relationships between the requirements, software design, code and validation tests. The BAC South West software team has an archive of traceability relationships for the previous versions of the mission computer. The FET Systems software team does not employ a specific traceability tool, though they do employ a spreadsheet tool to demonstrate their test coverage.

9.2.5 The Introduction of the TDC

For the development of the next version of the aircraft's mission computer software, the requirements team (BAC North West) and the software design team (BAC South West), agree to work according to the TDC: the requirements team acting as the upstream team and the software development team acting as the downstream team. Both teams agree to a shared file system to store shared artefacts and a traceability database that has a schema (described in Appendix B) that implements the traceability structures described in Chapter 8.

The following sections will work through the TDC protocol stages (Section 7.3).

- In the <u>Contract Initiation</u> stage (Section 9.3), the terms of the work that is to be undertaken are defined.
- In the <u>Problem Discourse</u> stage (Section 9.4), both teams clarify and agreed the problem artefacts.
- In the <u>Proposed Solution</u> stage (Section 9.5), the BAC South West software team demonstrates to the BAC North West requirements team how they intend to tackle the problem.
- In the <u>Development and Refinement</u> stage (Section 9.6), BAC South West software team produces and refines the solution.

- In the Completion stage (Section 9.7), the BAC South West software team demonstrates to the BAC North West requirements team that they have satisfied the contract.

For each stage, the working practices of the BAC requirements team and the BAC software team will be compared with the working practices of the BAC requirements team and FET Systems.

9.3 Initiation

The Initiation stage is concerned with defining the contractual terms of the work that is to be undertaken. The information that is required to be recorded and agreed at this stage of the contract is described in Table 3.

1	Activity Description	The production of the Accipiter 300 mission computer software.
2	Stakeholders	Upstream Team: members of the requirements team (BAC North West) (Figure 9-4) Downstream Team: members of the mission computer software development team (BAC South West). (Figure 9-4)
3	Problem Artefacts	The aircraft mission computer software requirements and UML Use Case Diagrams (refer to section 9.3.1)
4	Planning	Delivery dates and milestones for the mission computer software. (Refer to Figure 9-3 Mission Computer Development Plan.)
5	Arbitration Procedure	The Chief Engineer for Accipiter 300 is identified as the arbitrator for any disputes. Teams are required to describe their position with respect to any conflict. Teams are required to present information, such as an impact analysis, that supports their position. Team are required to offer possible solutions to the conflict.

Table 3 TDC Initiation Information

9.3.1 Example Mission Computer Problem Artefacts

The following are examples of the problem artefacts which are required at contract initiation. For example, Tape Interface Requirements (Table 4), UML

Use Case (Figure 9-2), Delivery Plan (Figure 9-3) and Stakeholder Organisation Charts (Figure 9-4).

Unique ID	Tape Interface Requirements
10	Before Flight: Flight Plan Down Load and PDC Cartridge Insert
10.1	The Pilot will insert the Flight Plan Data 4mm tape cartridge into the mission computer.
10.2	The Pilot will select from the mission computer touch screen the Download Flight Plan option
10.3	The Mission Computer will detect the presence of a correctly formatted Flight Plan tape cartridge. (For the format of Flight Plan tape cartridge refer to Appendix G: Data Formats)
10.4	If a Flight Plan tape is not present or not of the correct format then the Mission Computer will display – "Download Aborted" and will eject the tape cartridge if present.
10.5	The Mission Computer will read and validate each waypoint from the tape. Writing the contents of each way point to FlightPlan.dat data file (For the format of FlightPlan.dat refer to Appendix G: Data Formats)
10.6	If a waypoint is corrupt or the total number of waypoints does not agree with the number in the taper header then the Mission Computer will display – "Download Aborted" and will eject the tape cartridge.
10.7	The Mission Computer will display – "Download Successful" once the FlightPlan.dat file has been written to the hard disk.
10.8	The Mission Computer will eject the Flight Plan data tape cartridge.
10.9	The Pilot will insert a blank formatted tape data cartridge, for the recording of the aircraft's positional data, into the Mission Computer.
10.10	The Pilot will select – "Insert PDC" PDC – Positional Data Cartridge.
10.11	The Mission Computer will detect the presence of a correctly formatted Positional Data 4mm tape cartridge. (For the format of Flight Plan tape cartridge refer to Appendix G: Data Formats)
10.12	If a Positional Data tape is not present or not of the correct format then the Mission Computer will display – "PDC Insert Failed" and will eject the tape cartridge if present.
10.13	On the successful insertion the Mission Computer will display – "PDC Inserted"

Table 4 Requirements

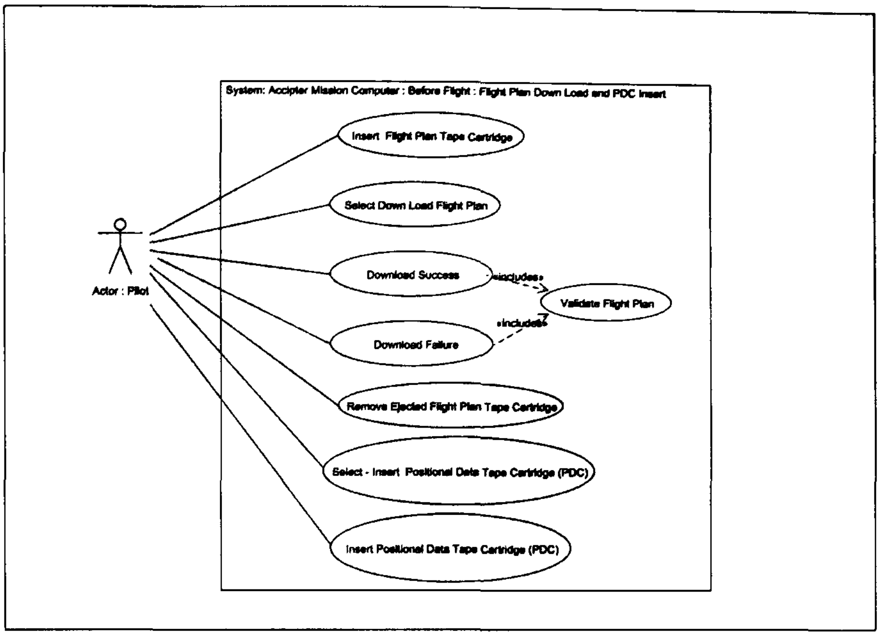

System: Accipter Mission Computer : Before Flight : Flight Plan Down Load and PDC Insert
Actor : Pilot
Insert Flight Plan Tape Cartridge
Select Down Load Flight Plan
Download Success
«includes»
Validate Flight Plan
«includes»
Download Failure
Remove Ejected Flight Plan Tape Cartridge
Select - Insert Positional Data Tape Cartridge (PDC)
Insert Positional Data Tape Cartridge (PDC)

Figure 9-2 UML Use Case Diagram: Down Load Flight Plan - Insert PDC

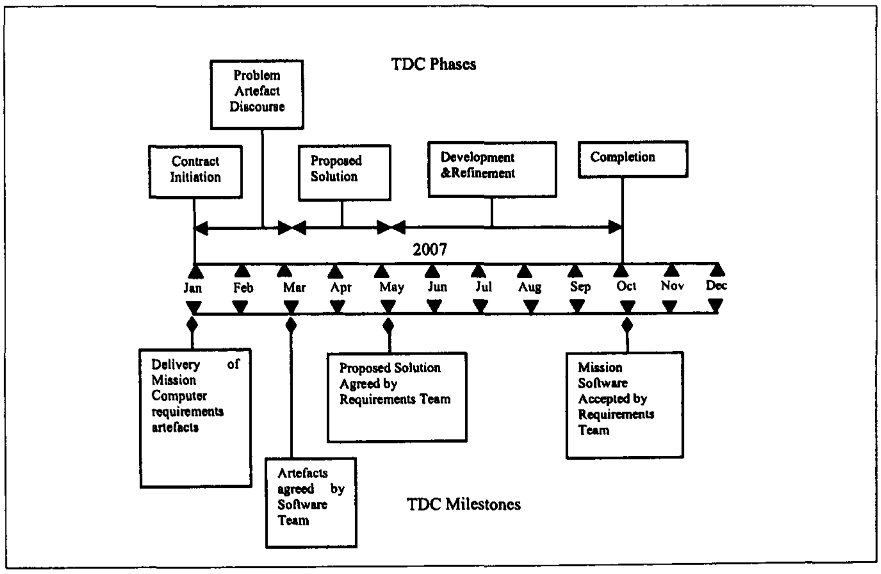

TDC Phases
Problem Artefact Discourse
Contract Initiation
Proposed Solution
Development &Refinement
Completion
2007
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Delivery of Mission Computer requirements artefacts
Artefacts agreed by Software Team
Proposed Solution Agreed by Requirements Team
Mission Software Accepted by Requirements Team
TDC Milestones

Figure 9-3 Mission Computer Development Plan

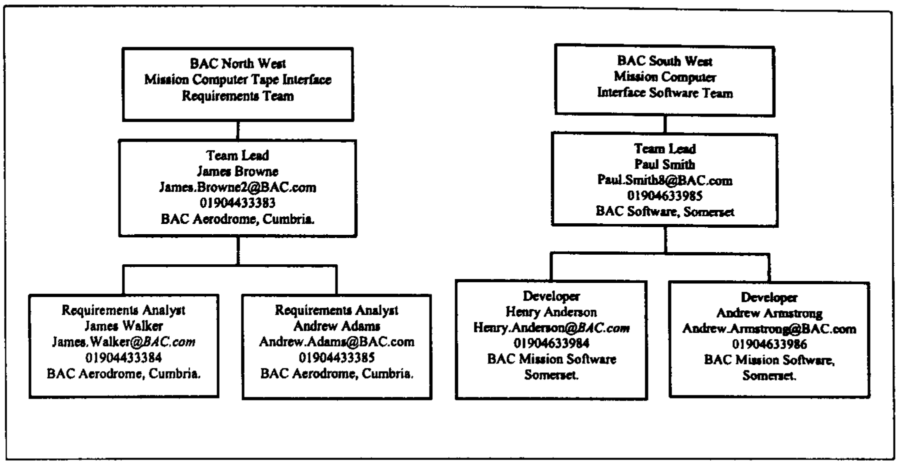


Figure 9-4 Organization Chart

9.3.2 Comparing and Contrasting with FET Systems' Approach

At the start of the project, the FET Systems software team will have established the activity description (1), problem artefacts (3) and planning information. However, FET Systems software team will not have identified all the relevant stakeholders (2) and a method of arbitration (5). From the observation made during the traceability survey, none of the development processes considered the problem of conflict between teams. For these development processes, there was no requirement to define an arbitration process and this is the case for FET Systems. It was also observed that in many cases personal contact between teams was often limited to team leaders. Failing to identify a method of arbitration may result in the poor resolution of inter-team conflicts. Also by failing to establish all stakeholders, the efficiency of communications between the two teams will be reduced.

9.4 Problem Discourse

The Problem Discourse stage aims to clarify any issues with the problem artefacts and to obtain the agreement of the downstream developer team that the artefacts are suitable for the production of an initial solution. It is at this stage, that the BAC requirements team start to populate the traceability structures. The first structure to be populated is the logical decomposition structure (Section 8.7). This involves identifying all the artefacts and recording their decomposition. The logical decomposition structure acts as an index to the problem artefacts, allowing the engineers to navigate the composition of the problem. A suitable method of decomposing the Accipiter's requirements would be to decompose according to the parent document structure. In this case, each requirement statement would become an artefact. For example, Figure 9-5 represents the decomposition of the Accipiter's textual requirements.

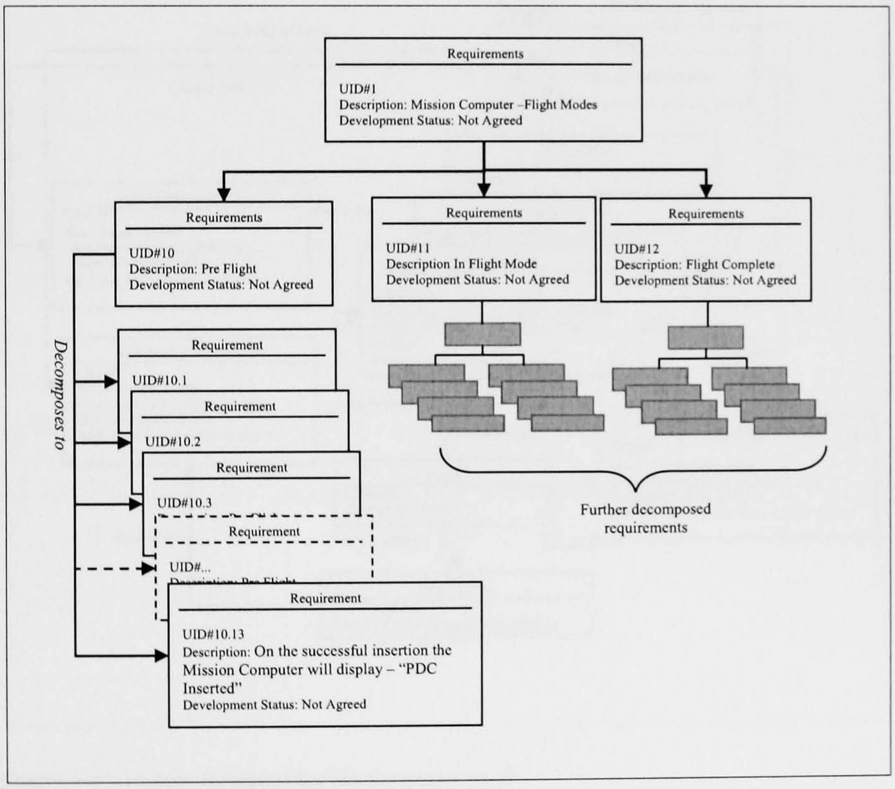

Requirements
UID#1
Description: Mission Computer - Flight Modes
Development Status: Not Agreed
Requirements
UID#10
Description: Pre Flight
Development Status: Not Agreed
Requirements
UID#11
Description In Flight Mode
Development Status: Not Agreed
Requirements
UID#12
Description: Flight Complete
Development Status: Not Agreed
Decomposes to
Requirement
UID#10.1
Requirement
UID#10.2
Requirement
UID#10.3
Requirement
UID#...
Requirement
UID#10.13
Description: On the successful insertion the Mission Computer will display – "PDC Inserted"
Development Status: Not Agreed
Further decomposed requirements

Figure 9-5 Logical Decomposition of the Accipiter Requirements

Each artefact has a development status (Not Agreed, Agreed or Deferred) that records the state of agreement between the two teams on the suitability of artefact for the production of solution.

The second structure to be populated is the Artefact structure (refer to section 8.9). This structure records the ownership and development history for each artefact. For example, Figure 9-6 show how the Artefact structure is applied to textual requirement 10.13. These traceability structures allow queries to be performed that help the BAC software team determine the suitability of the requirements.

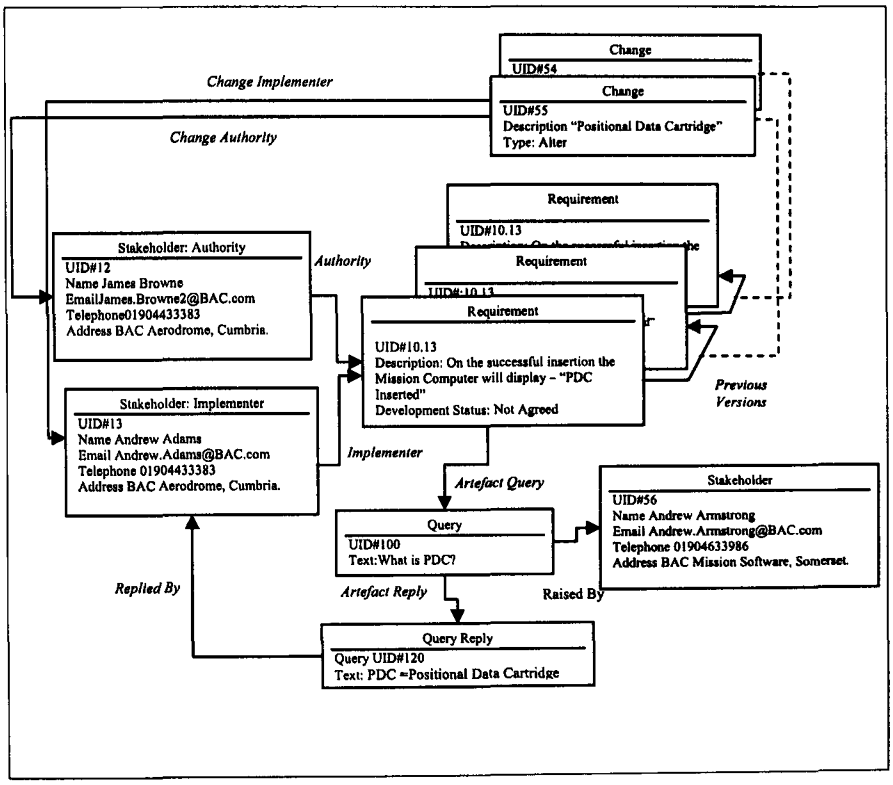


Figure 9-6 Artefact Structure for Requirement 10.13

The queries fall into three groups,

- Information Queries: This group of queries involve the determination of the requirement and its attributes, such as the implementer (or in this case the writer) of the requirement and the technical authority for the requirement. (Example queries can be found in Appendix C.)
- Dialog Queries: This group of queries involves creation and recording of dialog between the two teams with respect to issues related to the requirement. (Example queries can be found in Appendix C.)
- Status Queries: This group of queries involve the determination and setting of the development status of a requirement. (Example queries can be found in Appendix C.)

As requirements are normally specified in text, they can be recorded in the description attribute of the artefact structure. Where a requirement is specified by a drawing or a diagram, the description attribute will describe the diagram and the location attribute will record the location of the diagram. This approach was adopted by many of the projects in the traceability survey.

As stated in section 8.5 the Artefact structure is derived from Gotel's Contributions Structures. Gotel claimed the following benefits from the implementation of such structures in a development environment:

Artefact Ownership, Commitment and Responsibility: The Artefact structure defines ownership (Technical Authority and Implementer). This impels these stakeholders to commit to a position on the development state of an artefact. The result of this commitment is that the responsible stakeholder would take a position and engage in discussions with respect to changes to an artefact. In this illustration, the BAC requirements team members are committed to being a technical authority or implementer of the Accipiter's requirements.

Artefact Contribution: The ability to record the contribution made by each stakeholder to an artefact is found to aid change discussions and allows project managers to track progress and allocate artefact ownership. The Artefact structure records the original implementer and any changes made. For each change to an artefact, the Artefact structure records the stakeholder who contributed. In this illustration, the Artefact structure will record the changes the BAC requirements team members make to requirement artefacts.

Uncovering Hidden Details and Undocumented Events: The use of traceability structures often results in the uncovering of hidden artefact details and misunderstandings between stakeholders. The Artefact structure allows the recording of queries and replies for each artefact. In this illustration, this feature can be employed by the BAC software team asking questions of the requirements and the BAC requirements team replying to those queries.

Agreement: The use of traceability structures help stakeholders to come to an agreement with respect to the development status of an artefact. Each Artefact has an attribute that records the agreed development status. In this illustration, the development status attribute is employed to demonstrate which artefacts the BAC software team have agreed to be suitable for development.

9.4.1 Comparing and Contrasting with FET Systems' Approach

On reading the requirements, the FET Systems software engineers will have similar questions on the new functionality to that of the BAC software team. The FET Systems software team takes a traditional approach, collecting its questions, and arranging a requirements' review meeting with the BAC requirements team to obtain clarification. By failing to identify all the relevant stakeholders, the FET software engineers may target their questions at the wrong engineer. This is in contrast to the use of the traceability database that allows the targeting of questions to the correct stakeholder. Such a shared traceability database may even mitigate the need for a review meeting. Given the distances between development sites, this would reduce development costs. However, if a review meeting is required then the output from the traceability database, such as the raised queries and answers, will help in the review of the requirements.

9.5 Proposed Solution

The Proposed Solution stage starts once all the problem artefacts, the requirements, have been agreed or deferred to later release. This stage allows the BAC software team to demonstrate how their prototype design will address the requirements.

Software designs are commonly described using diagrams such as UML package or deployment diagrams (for example, Figure 9-7 and Figure 9-8). Diagrams cannot be decomposed in the same way that the textual requirements were decomposed in the previous phase.

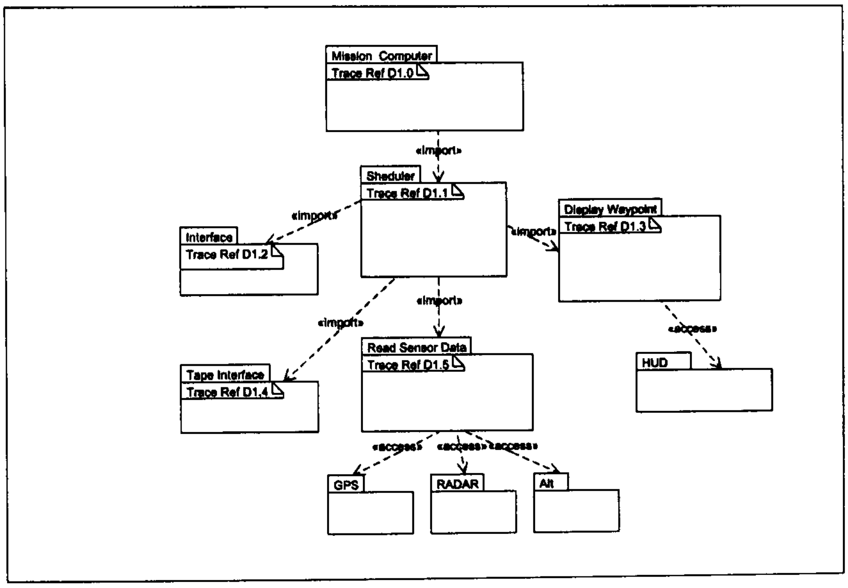


Figure 9-7 Prototype Package Decomposition

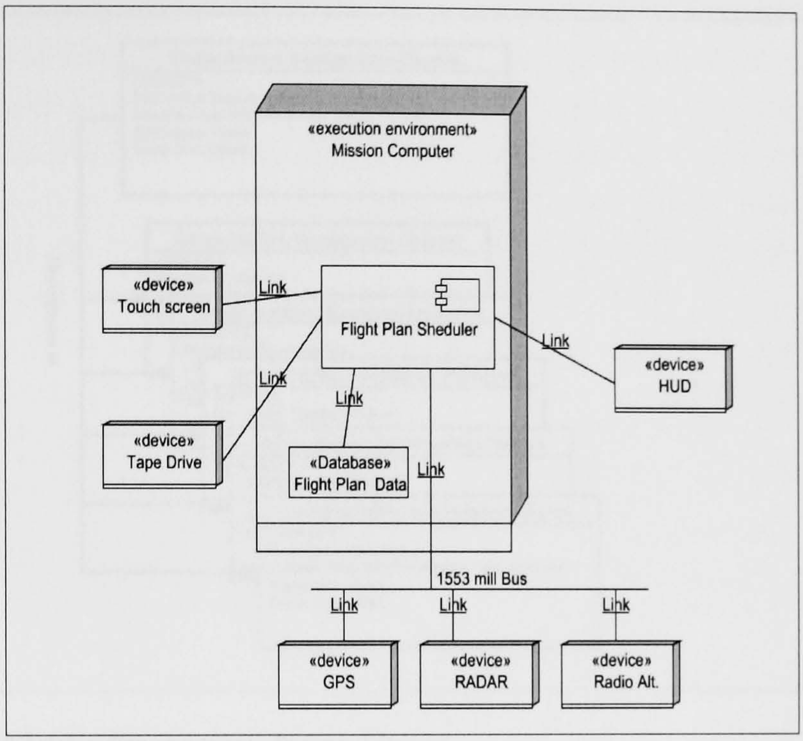


Figure 9-8 Prototype Deployment Diagram

Artefacts in the diagrams are identified by marking them with unique id, for example in Figure 9-7 each package is marked with an identifier. In the case of diagrams, the Artefact Decomposition structure becomes a flat structure that lists the artefacts described in the diagram (Figure 9-9). To determine the true relationship between artefacts the engineer will be required to refer to the original diagram.

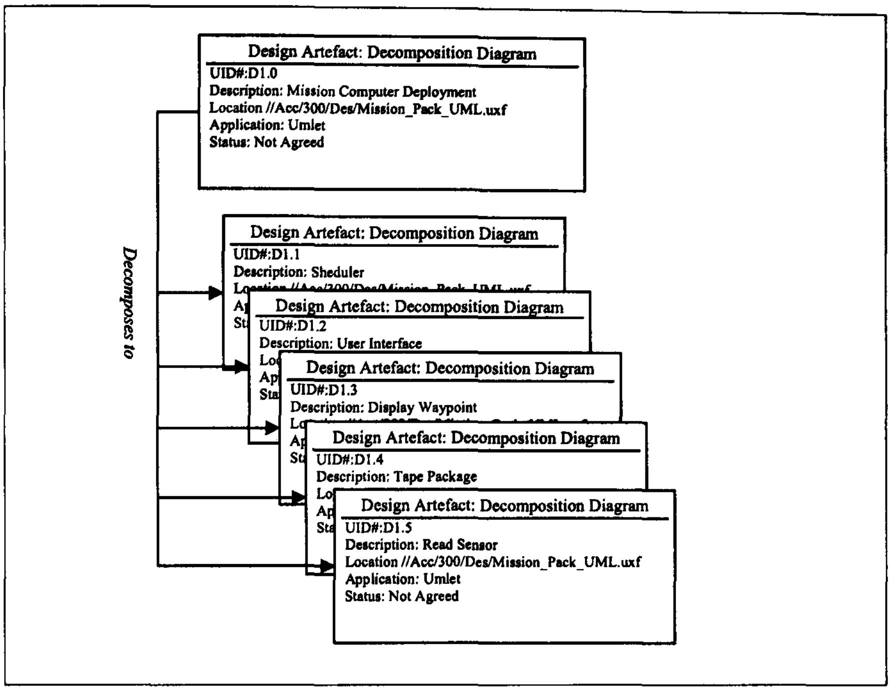
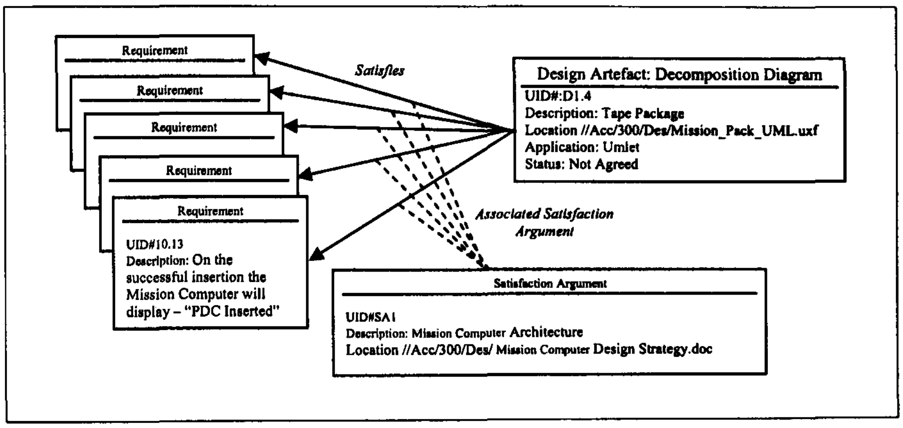

Design Artefact: Decomposition Diagram
UID#:D1.0
Description: Mission Computer Deployment
Location //Acc/300/Des/Mission_Pack_UML.uxf
Application: Umlet
Status: Not Agreed
Decomposes to
Design Artefact: Decomposition Diagram
UID#:D1.1
Description: Sheduler
Design Artefact: Decomposition Diagram
UID#:D1.2
Description: User Interface
Design Artefact: Decomposition Diagram
UID#:D1.3
Description: Display Waypoint
Design Artefact: Decomposition Diagram
UID#:D1.4
Description: Tape Package
Design Artefact: Decomposition Diagram
UID#:D1.5
Description: Read Sensor
Location //Acc/300/Des/Mission_Pack_UML.uxf
Application: Umlet
Status: Not Agreed

Figure 9-9 Artefact Decomposition - Package Diagram

Once the design artefacts have been identified, the Artefact structure is populated for each design artefact. In the same way as the requirements artefacts, the design artefact structures records the ownership and development history for each design artefact.

To demonstrate how the prototype design will address the requirements, the BAC software design team populates the Artefact Satisfaction structure (refer to Section 8.6), recording the relationships between the requirements and design artefacts. In the cases where it is not clear what contribution a design artefact makes to the satisfaction of a requirement (or a collection of requirements), a satisfaction argument may be required. In this illustration, the BAC software team have written a document (Mission Computer Architecture) that outlines the reasoning behind the design. The Mission Computer Architecture document describes the engineering reasoning for the design, the decomposition of the functional components that comprise the design and a detailed description of the functionality of each design component. For design components that are safety critical the component textual descriptions are supplemented with a GSN argument (refer to 8.2.1). In this example, the requirements-tape package traceability links have an associated trace to the sections of the Mission Computer Architecture document that describe the tape interface (Figure 9-10).



Requirement
Requirement
Requirement
Requirement
Requirement
UID#10.13
Description: On the successful insertion the Mission Computer will display - "PDC Inserted"
Satisfies
Design Artefact: Decomposition Diagram
UID#:D1.4
Description: Tape Package
Location //Acc/300/Des/Mission_Pack_UML.uxf
Application: Umlet
Status: Not Agreed
Associated Satisfaction Argument
Satisfaction Argument
UID#SA1
Description: Mission Computer Architecture
Location //Acc/300/Des/ Mission Computer Design Strategy.doc

Figure 9-10 Artefact Satisfaction: Requirements and Tape Package

The TDC requirement that the BAC software team be able to demonstrate the validity of the design will entail the population of the Artefact Validation structure (refer to section 8.8) for the design artefacts (Figure 9-11). The design Artefact Validation structure records how each design artefact is to be tested.

Also at this point that the BAC software team start to write code. As with the requirement and design artefacts, the code is described by artefact decomposition and artefact structures. Artefact Satisfaction structures are employed to record the relationship between the design and code artefacts. In this case, it is a simple one to one relationship between code and UML package (Figure 9-11).

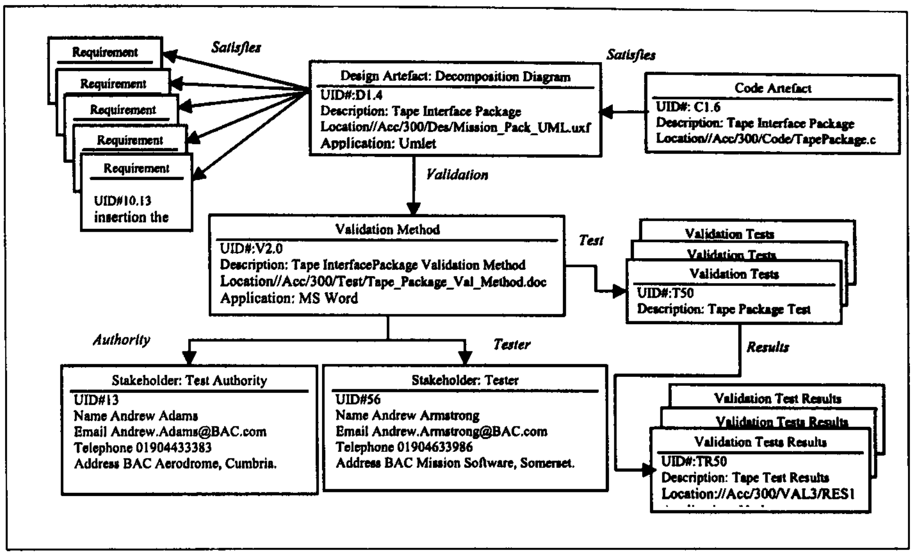

Requirement
Requirement
Requirement
Requirement
Requirement
UID#10.13
insertion the
Satisfies
Design Artefact: Decomposition Diagram
UID#:D1.4
Description: Tape Interface Package
Location//Acc/300/Des/Mission_Pack_UML.uxf
Application: Umlet
Satisfies
Code Artefact
UID#: C1.6
Description: Tape Interface Package
Location//Acc/300/Code/TapePackage.c
Validation
Validation Method
UID#:V2.0
Description: Tape InterfacePackage Validation Method
Location//Acc/300/Test/Tape_Package_Val_Method.doc
Application: MS Word
Test
Validation Tests
Validation Tests
Validation Tests
UID#:T50
Description: Tape Package Test
Authority
Tester
Results
Stakeholder: Test Authority
UID#13
Name Andrew Adams
Email Andrew.Adams@BAC.com
Telephone 01904433383
Address BAC Aerodrome, Cumbria.
Stakeholder: Tester
UID#56
Name Andrew Armstrong
Email Andrew.Armstrong@BAC.com
Telephone 01904633986
Address BAC Mission Software, Somerset.
Validation Test Results
Validation Tests Results
Validation Tests Results
UID#:TR50
Description: Tape Test Results
Location://Acc/300/VAL3/RES1

Figure 9-11 Artefact Validation: Tape Package

In this illustration, an assumption (9.2.4) was made that the BAC software team had employed a traceability tool to record the relationships between the requirements, software design, code and validation tests for previous products. This assumption has been made to allow the demonstration of the benefits that can be achieved from traceability when developing product families. The weakness of this assumption will be considered in the next section.

The Automotive Sensor case study (Chapter 5) demonstrated the benefits in the use of traceability in the selection of a base product for the development of a new product. For the production of a new sensor, the new requirements were compared against the exiting products to determine which sensor would be a suitable base product. This use of traceability enabled the software engineers to reuse existing software and tests, thereby reducing their workload.

The selection of a base product is a complex process, as the engineers have to take into account the issues relating to the removal and addition of functionality. However, the TDC traceability structures can aid the process. Having the requirements recorded in the Artefact Decomposition structure allows them to be compared with the requirements, held in the same structures, for previous releases of the mission computer software. This is achieved by a tree traversal of the new requirements and previous released requirements, comparing the contents of each artefact node. From this traversal, a list of differing requirements is obtained for each of the previous releases. For this illustration it was found, by manual inspection of the differing requirements, that the requirements for the Accipiter 250 (Figure 9-12) were the best match and would be a suitable base product for the new Accipiter 300.

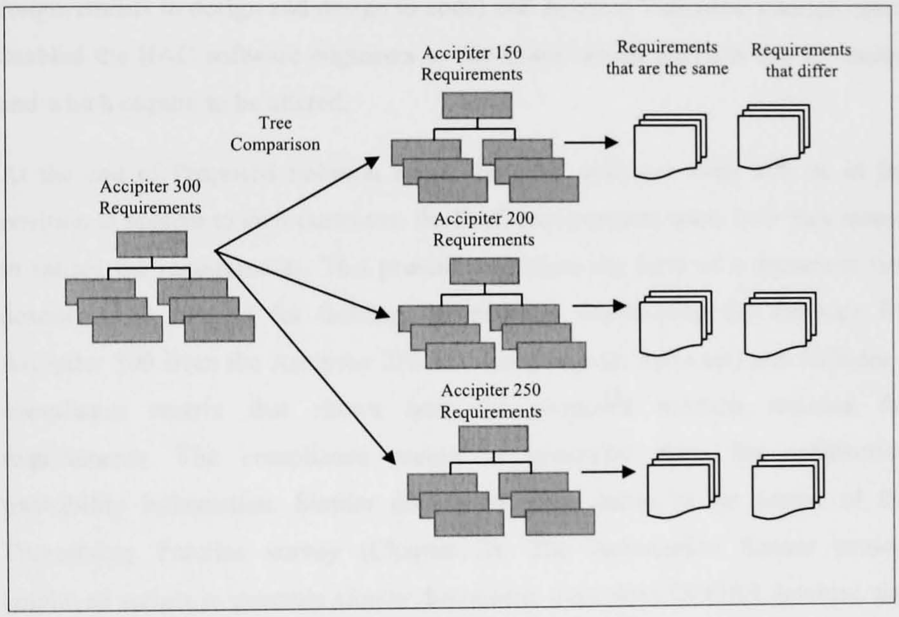

Accipiter 150 Requirements
Requirements that are the same
Requirements that differ
Tree Comparison
Accipiter 300 Requirements
Accipiter 200 Requirements
Accipiter 250 Requirements

Figure 9-12 Comparison of Mission Computer Requirements

The process is repeated to determine the affected Accipiter 250 code modules. In this case, the Artefact Satisfaction structures that record how the Accipiter 250 code modules satisfy the affected design artefacts are examined. In this case, there is a simple one to one relationship between the design packages and code.

The determination of which validation tests can be reused can obtained from examining the relationships between the design artefacts not affected by the requirement changes and the validation methods (similar to Figure 9-11). This is achieved by examining the Artefact Validation structure that records the relationships between validation methods and design artefacts. This structure will also be employed to determine the individual tests that comprise a validation method.

The traceability structures, Artefact Decomposition (requirements, design and code) Artefact (requirements, design and code), Artefact Satisfaction (requirements to design and design to code) and Artefact Validation (design) have enabled the BAC software engineers to determine which artefacts can be reused and which require to be altered.

At the end of Proposed Solution stage, the BAC software team will be in the position to present to their customer, the BAC requirements team, how they intend to satisfy the requirements. This presentation takes the form of a document that describes the strategy for tackling the problem (developing the software for Accipiter 300 from the Accipiter 250 mission computer software) and includes a compliance matrix that shows how the proposed solution satisfies the requirements. The compliance matrix is generated from the satisfaction traceability information. Similar documents were found in the course of the Traceability Practice survey (Chapter 3). The Automotive Sensor project employed scripts to generate similar documents from their DOORS database and the MBDA projects manually produced a document known as a "Design Reply".

The TDC requires the BAC requirements team to act as the customer in this contract and therefore the requirements team has to accept the proposed solution or to reject it, indicating to the BAC software team where the solution fails to satisfy the requirements.

In this illustration, the BAC requirements team accepts the proposed solution and the contract proceeds to the next stage, development and refinement.

9.5.1 Comparing and Contrasting with FET Systems' Approach.

For the development of the land-based mission planning software, the FET Systems software team will be in a similar position and the team will aim to base their new product on existing code. The lack of traceability may mean that the FET Systems software team will not be able to identify efficiently a suitable base product and which parts of that product are required to be changed. However, the FET Systems software has not had to create and populate a traceability database.

A weakness in this illustration is that the BAC software team had employed a traceability tool to record the relationships for previous products. The demonstrated benefits are a result of having a traceability database for previous products. What would happen if there were no previous products? In such a case, it could be argued that the effort expended in creating and populating the database out weighs any benefits such as the generation of a compliance matrix. Nevertheless, this argument is countered by considering the role of traceability in the TDC, that of a means of determining the impact of change and to provide a basis for the negotiation of change during development.

In contrast to the BAC software team, the FET Systems software team does not have to gain the acceptance of their solution by the BAC requirements team. This is a lost opportunity as the BAC requirements team may identify flaws in FET Systems' initial approach to the requirements. Failure to identify flaws early in the development of the software may prove to be costly.

9.6 Development & Refinement

Once the BAC requirements team agree the proposed solution, both teams are allowed to request changes to the requirements or the proposed solution. In this illustration the BAC requirements team request a change to replace the tape data cartridges for a SD Secure Digital (SD) High Capacity (HC) non-volatile memory card (Table 5 and Figure 9-13). The SD card will act as a virtual hard disk and there will be no requirement to validate the data held on the card. The use of the SD memory card means that a second tape cartridge, for the recording of the positional data will no longer be required.

Unique ID	Change	Tape Interface Requirements
10		Before Flight: Flight Plan Down Load and PDC Memory Card Insert
10.1	Altered	The Pilot will insert the SD (HC) Memory Card into the mission computer.
10.2		The Pilot will select from the mission computer touch screen the option - Download Flight Plan
10.3	Altered	The Mission Computer will detect the presence of a SD(HC) Memory Card. (For the format of Flight Plan refer to Appendix G: Data Formats)
10.4	Altered	If a SD (HC) Memory Card is not present or of the correct format (For the format of Flight Plan refer to Appendix G: Data Formats) then the Mission Computer will display – "Download Aborted".
10.5	Removed	
10.6	Removed	
10.7	Altered	The Mission Computer will display – "Download Successful"
10.8	Removed	
10.9	Removed	
10.10	Removed	
10.11	Removed	
10.12	Removed	
10.13	Removed	
10.14	New	Waypoint data will be encrypted on the Secure Digital Memory Card
10.15	New	Positional Sensor data will be encrypted on the Secure Digital Memory Card

Table 5 Requirement Changes

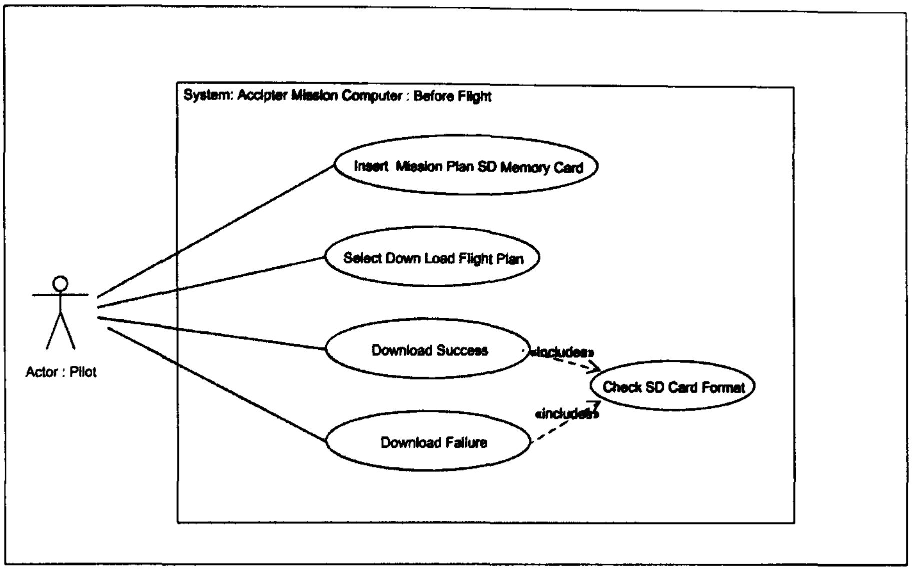

System: Accipter Mission Computer : Before Flight
Insert Mission Plan SD Memory Card
Select Down Load Flight Plan
Download Success
«includes»
Check SD Card Format
«includes»
Download Failure
Actor : Pilot

Figure 9-13 New Use Case Diagram

Table 5 illustrates a point; often changes are not clear and may be not functionally correct. In this case, the BAC requirements team have aimed to simplify the interface by removing the need to insert a separate storage media for recording the positional data. The positional data is recorded on the same SD memory card that stores the flight plan waypoints. The BAC requirements team has also included two new requirements 10.14 and 10.15 and it is unclear how they influence the new media interface.

The traceability structures are employed to negotiate these changes. The BAC requirements team updates the Artefact Structure for each of the affected requirement Artefacts. In this case the change description and type, artefact description, technical authority for the change and the implementer of the change are recorded (for example, refer to Figure 9-6). As these changes have not been agreed, the Agreed Status is set to "Not Agreed".

The BAC requirements team employs the traceability structures to determine the design artefact stakeholders affected by the requirement changes. This is achieved by employing the Artefact Satisfaction structure that records the satisfaction relationships between requirements artefacts and design artefacts (for example, refer to Figure 9-10) to determine which design artefacts are affected. For each affected design artefact, its Artefact Structure is employed to determine the Authority and Implementer for the artefact. For the two new requirement artefacts, 10.14 and 10.15 (refer to Table 5) there will no corresponding design artefact. In this case, the authority and implementer of their parent artefact 10.0 is determined. The BAC requirements team now notifies the affected BAC software team members of the proposed changes to the requirements.

The BAC software team is in a similar position as they were in the Problem Discourse stage (section 9.4). The BAC software team employs the updated Artefact and Artefact Decomposition structures that describe the requirements to perform Information, Dialog and Status Queries on the changed requirement artefacts. In this way the BAC software team clarify the changes to the requirements.

In conjunction with the process of clarifying the requirements, BAC software team employs the traceability structures to determine the full impact of the changes. This entails determining the true impact of the changes, the impact on the testing and code.

To determine the true impact of the changes the BAC software team will be required to refer to the Satisfaction Argument (refer to Figure 9-10) for each affected requirement – design artefact pairing (refer to Appendix C, example Satisfaction Queries). This information will help the engineer to determine the contribution the design artefact makes to the affected requirement and therefore the impact of the change on the design artefact. The design Artefact Decomposition structure (refer to Figure 9-9) is employed to help to determine the impact of the changes on any child artefacts. The BAC software team employs the Artefact Validation structure (refer to Figure 9-11) to determine the impact on the validation tests. The impact on the code is determined by employing the satisfaction structure that records the relationships between code and design artefacts (refer to Figure 9-11). Armed with the impact information both teams (requirements and software) now enter into negotiations on the implementation of the changes. In the cases where these negotiations fail, the teams may call upon the services of the arbitrator who was defined in the initiation phase of the contract. In this illustration, both teams agree the changes to the requirements and an extension, in conjunction with their respective project management, to a new completion date.

9.6.1 Comparing and Contrasting with FET Systems' Approach.

The engineers at FET Systems will be faced with similar issues with respect to the replacement of tape cartridges by a SD memory card. Without the aid of the traceability structures it may be difficult for the engineers to clarify the requirements changes efficiently. If the membership of the FET Systems' engineering team changes during development then the lost product knowledge may reduce the efficiency of determining the impact of the changes. The FET Systems engineers are not protected by the TDC, the BAC requirements team is not required to negotiate the impact of the changes and any resulting conflict will be required to be resolved by the project managers who may not have the technical expertise to resolve the conflict correctly.

9.7 Completion

The aim of the Completion stage of the TDC is to demonstrate what has been successfully completed. Traditionally, this is where traceability becomes apparent in most development processes usually in the form of a requirements/test compliance matrix.

The TDC imposes responsibilities on the development teams. It is the responsibility of the BAC software team to demonstrate, by testing, that the software addresses the requirements. The BAC requirements team has the responsibility of accepting the evidence and confirming the completion of the contract.

One of the major benefits from populating the traceability database during development becomes apparent at this stage. It is possible to generate a compliance matrix, for example Figure 9-14, from the data held in the traceability database. The Automotive sensor project (Chapter 5) generated a number of different reports (refer to Figure 5.3) from their traceability database to demonstrate to their customer that they had satisfied the requirements. Such reports are employed by the BAC software team to demonstrate to the BAC requirements team that they have completed the contract.

9.7.1 Comparing and Contrasting with FET Systems' Approach.

The FET software team will be required to produce evidence, usually in the form of compliance matrices, that their software satisfies the requirements. As the FET software team have no traceability database these documents will have to be produced by hand. This will be a laborious task prone to errors. The FET software team also have a different customer compared to the BAC software team. The FET software team customer is the Accipiter 300 systems integration team, to whom they deliver their software. This means that the FET software team does not employ the expertise of the BAC requirements team in the validation of the software. Therefore, any issues or problems with the software are propagated to the development next stage: systems integration.

REQ UID	Requirement	Satisfied By Design Artefact	Satisfied By Code Artefact	Val MetUID	Validation Method	Test UID	Test Description	Results Location
REQ 10:15	Aircrafts Positional Sensor data will be encrypted on Secure Digital Memory Card	UML Deployment Diagram: Sensor Read	Sched_Sensor_Read.c	VAL30	Positional Sensor Simulator harness employed to mimic actual input			
			Read_Radar_Data.c			T56	Recording of encrypted of radar data	/Acc300/VAL30/T56/RES1
			Read_GPS_Data.c			T57	Recording of encrypted of GPS data	/Acc300/VAL30/T57/RES4
			Read_Altim_Data.c			T58	Recording of encrypted of Altimeter data	/Acc300/VAL30/T58/RES3
						T59	Recording of encrypted data for all sensors	/Acc300/VAL30/T59/RES1

Figure 9-14 Example Compliance Matrix

9.8 Summary

This illustration demonstrates how Traceability can be beneficial the development process and to engineers who are performing that process and therefore overcoming the Traceability Benefit Problem. The TDC gives a purpose to recording the traceability information. The illustration shows that the TDC can:

- Aid the engineer with the selection of a suitable base product.
- Aid the engineer with the communication and negotiation of change.
- Aid the engineer in the demonstration of the validity of the final product.

This chapter is only an illustration that does not set out to prove or disprove how the TDC would be beneficial in practice. The next chapter examines the issues and practical implications of demonstrating that the TDC is as beneficial as it is claimed to be.

Chapter 10 Lessons Learnt and Future Work

10.1 Introduction

This chapter summarises the achievements and the problems overcome in the course of this work. The chapter describes the history of the development of the ideas present in this thesis and finally, discusses how the work presented can be extended further.

Traceability, as a research topic, had declined in popularity with the academic community by the 2000s and this is reflected in the number of papers published on the topic: the bulk of the papers being published in the late 1980s and 1990s (Citeseer – Year of Publication of Cited Papers). The zenith of traceability research coincided with the general availability of relational databases that allowed the recording and manipulation of links between textual objects. This resulted in a number of Traceability tools, the most notable being DOORS [DOORS 2007] and RTM [RTM 2007]. Yet, reports from the DCSC [DCSC 2007] customer companies suggested that there were still issues in recording Traceability information in an industrial context. These issues were concerned with encouraging engineers to record and maintain Traceability information.

10.2 Identifying the Problem

Initially, it was thought that the engineers were not recording and maintaining their Traceability information due to the data entry burden imposed by the Traceability tools. This hypothesis appeared to be backed up by reviews of the use of Traceability tools in an industrial context [Ramesh 1998] [Gotel 1995;Gotel and Finkelstein 1994] (as discussed in the summary of Chapter 3). The solution seemed relativity straightforward: find a way of reducing the data entry burden that the Traceability tools placed on the engineers. One possible solution to reducing the data entry burden was to remove the need to transpose data from development tools to traceability tools. This resulted in initial investigations into tool integration data models such as AP233 [Herzog 2000] and MATra [Mason 1999] and data transfer and sharing technologies such as XML (as discussed in Chapter 2).

At the time the research reported in this thesis was beginning, XML and in particular XML-Xlink [Xlink 2007] was being promoted as a means of linking documents. Xlink was a new technology that allowed the creation of bidirectional links between documents. These links could also be given meaning with the addition of meta-data, therefore allowing the sorting and classification of links between documents. The development of XML opened up new opportunities and a number of researchers [Alves-Floss et al. 2002] [Collard et al. 2002] [Anderson et al. 2002] [Zisman et al. 2003] [Nentwich et al. 2002] proposed ways of employing these XML technologies to create traceability information frameworks. XML appeared to be a promising technology: if all the engineering documents were in a known XML format then XML links could be generated between them with little effort. This appeared to be a way of reducing the burden of data entry on the engineers.

Though the XML-Xlink approach had merit, it only addressed part of the problem of encouraging engineers to record Traceability data. It became apparent when talking to practicing engineers that the issues relating to the recording and maintenance of Traceability information were more complex and not just a technical data entry problem. More information was required on how engineers recorded and employed Traceability information and this resulted in a review of Traceability practices (Chapter 3).

10.3 The Importance of Observation

Before the Survey of Traceability Practices (Chapter 3) was conducted there were only two other comparable studies which were performed by Ramesh [Ramesh 1998] and Gotel[Gotel 1995; Gotel and Finkelstein 1994]. The aim of the Traceability Practices survey was to discover how projects perform traceability and to determine the truth behind the issues raised by the DCSC customer companies.

The survey was difficult to organise for a number of reasons. The first problem encountered was obtaining the permission of the companies to be surveyed. The initial list of companies included the DCSC customer companies MBDA, CSS & Programmes, Airbus and E&IS. One of the original aims of the survey was to compare and contrast the traceability practices of these aerospace companies with a civilian project, and so the Inland Revenue was approached for this purpose.

The Inland Revenue undertakes a number of large development projects in the North East. The consulting companies that develop the projects on behalf of the Inland Revenue refused access to their projects. The common reason for refusal was that if the survey identified any weakness in the development process then this could affect the consulting company's chance of gaining any further work from the Inland Revenue. The local consulting management would not take this risk; they preferred to keep their "dirty washing in house".

Consulting companies consider their development processes to be an integral part of their business and therefore are unwilling to allow their processes to be scrutinised by academics. One approach in gaining the trust of a commercial company is to highlight the benefits of the "free" research to their productivity and to promise to remove all references to the company or their product from any published work. For a good example of such an anonymous paper see [Berry and So 2006] that describes problems in the requirements engineering process for a very large software company. Care has to be taken though not to remove too much information and thereby render the publications useless. However, the Inland Revenue consulting companies refused this approach.

Ironically it is the military or technical companies, such as BAE SYSTEMS, TRW and Boeing, which publish the majority of papers on their working methods and appear to be more willing to demonstrate the strengths and weaknesses of their development process. These companies are also willing to discuss their practices with peers. This could be due to these organisations having well established publishing processes for editing and vetting.

Once access had been granted to the projects new problems arose. Care had to be taken when interviewing engineers. For example, many engineers were reluctant to have the interviews recorded. Many felt uncomfortable in criticising existing tools and working practices. This reticence was successfully overcome by asking the engineers to describe how they would improve their Traceability rather than asking them to list the problems.

As stated, the original data entry hypothesis appeared to be reasonable until the survey was conducted. The survey raised a number of factors that had an influence on Traceability practice, such as:

- Traceability Tools
- Development Practices
- Cost/Benefits
- Organisation & Culture
- Traceability Comprehension

The survey proved the importance of observing engineers performing their tasks at first hand and not solely relying on the limited academic literature in the development of a hypothesis. The survey, as demonstrated by the papers published from this thesis, has contributed to the understanding of the recording of Traceability information in an industrial context. The fact that so few industrial case studies or surveys are published is an indication of the difficulty of performing this type of research.

10.4 Traceability Benefit Problem

The main theme that arose from the survey was the perception by engineers and their line management that Traceability did not provide any benefit to the main development task. Many of the surveyed engineers considered the recording of Traceability information to be a hindrance to their main task. Some of the surveyed projects tackled this issue by having the recording of Traceability information performed by a separate team. This solution proved to be unsuccessful. By observing the engineers recording Traceability information, it became apparent that establishing a link was not always a simple process and often required domain knowledge. The only engineers which could reliably establish the correct Traceability links were the engineers who were directly involved in the development process. These observations resulted in the definition of the Traceability Benefit Problem (Chapter 4).

The definition of Traceability Benefit Problem has contributed to understanding the recording of Traceability as it demonstrates that the problem is not technology based. The observations have demonstrated the complex nature of recording of Traceability and highlighted that only the engineers who are involved in the development process can reliably record the Traceability information, therefore explaining the difficulties experienced by separate Traceability teams and automated link generation tools.

10.5 Traceable Development Contract

Having defined the problem the next stage was finding a possible solution. Again, the solution came from the survey.

The automotive sensor project undertaken by BAE SYSTEMS E&IS (Electronics and Integrated Solutions) (Chapter 5) addressed the Traceability Benefit Problem by developing a Traceability system which was integral to their development process and provided direct benefits both to the engineers performing the data entry and to the business. In essence, the E&IS engineers employed their traceability system to manage their customers demands and to improve their productivity.

The survey raised the problem of the coordination of changes to interface documentation. This was referred to by the engineers as "throwing the problem over the wall". This occurred when an upstream team imposed changes to their interface document without considering the impact of the changes on the downstream team. Development models (Chapter 6) often do not describe how teams should cooperate; it is assumed (wrongly) that they will work harmoniously. The survey highlighted the fact that due to development pressures teams do not always cooperate.

It became apparent that traceability information could be employed in the negotiation of change. The automotive case study provided an example of how traceability could be employed to negotiate change and improve productivity. However, the negotiation would require a set of rules or a protocol that both teams would abide by. This was the origins of the Traceable Development Contract (Chapter 7). This serendipitous combination of problems, the traceability benefit problem and the throwing the problem over the wall, had a common solution in the Traceable Development Contract. By keeping the contract generic, it made it applicable to all development interfaces and a combination of contracts may work towards to the elusive goal of end- to-end traceability.

Traceable Development Contract (TDC) data structures (Chapter 8) are a refinement of existing and proven traceability data structures. In this way, this work builds upon and extends existing Traceability work. The structures were kept simple and generic so enabling the TDC to be applied across all development boundaries. A criticism that can be made of previous traceability work is that it often lacks a development context: it is not clear when the structures should be populated, by whom and how the traceability data should be employed in the development process. The Traceable Development Contract protocol provides a context to these structures by stating who will populate the structures and how the data will be employed to benefit the local development process. The TDC protocol brings a purpose to these traceability data structures.

The TDC illustration (Chapter 9), loosely based on existing products and development practices, provided an opportunity to more fully demonstrate the benefits that development teams may obtain in adopting the contract. It also raised issues and provided some answers with respect to the evaluation of the TDC in an industrial context.

10.6 Further Work

This thesis has raised issues that require further investigation. The first and most obvious area for further work is the implementation and evaluation of the TDC in an industrial context. This is discussed in the next section (Section 10.6.1). The next candidate for future work is the further exploitation of the Traceability information to obtain development metrics (Sections 10.6.2 and 10.6.3). For example, the rate of change of Traceability information may provide an indication of the maturity of the solution. The arity and distribution of Traceability links may also give an indication of the state of evolution of the solution.

10.6.1 The Implementation of the TDC

The Implementation of the TDC will answer a number of questions, such as whether the TDC will provide the promised benefits. An implementation would also enable the practical testing and adjustment of the TDC protocol and the data structures.

The TDC illustration (Chapter 9) provides an example of how an assessment of a TDC implementation could be conducted. That illustration compared the working practices of two teams with comparable expertise and resources that were producing similar software from a common set of requirements. A full scale assessment would require a control team pairing and a team pairing that employs the TDC. Each team pairing would be required to have similar profile, technical expertise, staffing, tools, problem complexity and development timescales. Development timescales and problem complexity are important factors in the assessment of the TDC. The problem is required to have a complexity that will require the teams to discuss and clarify the problem domain issues. The assessment will be required to be made over a number of development cycles to determine the benefits obtained from the TDC and traceability data. Therefore, a suitable problem would be an evolving product or the development of product families. An assessment will require a survey of the engineer's views on the TDC. These views may be subjective and therefore measurable metrics are required to determine the true affect of the TDC. The following are examples of metrics that can be measured to determine how the TDC affects the performance of the software teams that have entered into the contract.

- Artefact Reuse. An outcome of the recording of the traceability data is that engineers will be able to determine which artefacts can be reused in the development of new products from existing products. Therefore, it would be expected that teams that employed the TDC would make greater use of existing artefacts compared with a control team that may only employ traceability in the latter stage of product development. The artefact reuse would be determined for the TDC team and the control team after every development cycle. If the TDC is successful, the team pairing employing the contract will show a higher percentage of artefacts reused compared to the control team pairing.

- Development Cycle Timescales. If the TDC is successful then the development times should be reduced compared to control team pairing. This is due to two factors, the greater reuse of artefacts and an increase in the efficiency the resolution of development problems. If the TDC is successful the teams employing the contract will have shorter development cycles compared to the control team.
- Trace Precision. The claim that the TDC makes the recording of traceability information beneficial to the immediate development process can be assessed by considering the change in Trace Precision (refer to section 4.2, equation 2). It is expected as the engineers gained experience of the benefits of the TDC and Traceability data they will increase their efforts in the development and maintenance of their traceability database. This should result in an increase in Trace Precision for their traceability database. The Trace Precision of the traceability database belonging to the TDC team pairing should be higher compared to the control team's database. To determine any increase in Trace Precision would require a periodic audit of the traceability database.

Such a project pairing may prove difficult to organise, as an industrial sponsor will require assurances that the assessment will not affect productivity. Therefore, a strong case for performing such an assessment will be required to convince an industrial sponsor to adopt the TDC. This case will have to argue that the implementation of the TDC will not have detrimental affect on their product and production timescales.

Another approach, that was adopted by Boehm in the evaluation of his WinWin Spiral Model [Boehm et al. 1998], was to employ groups of students in the development of a combined group project. Experiments based on student implementations are not without issues, such as the length and complexity of student projects, background experience of students and educational constraints. It can be argued that such student implementation can only give limited results. However, the student project approach should not be rejected as it can provide a useful environment to test prototype processes. The results of a student experiment can also be employed in the case presented to an industrial sponsor to implement the TDC in an industrial setting as previously described.

10.6.2 Solution Maturity

The standard IEEE 982 Standard Dictionary of Measures to Produce Reliable Software [IEEE 1988] states that this measure is used to quantify the readiness of a software product. Changes from a previous baseline to the current baseline are an indication of the current product stability. A baseline can be either an internal release or an external delivery. This definition can be applied to the products of each step of the development process, for example requirements, design, tests and code. Felici [Felici 2004] developed and demonstrated the idea of a simple maturity metric, which is based on the IEEE Software Maturity Index [IEEE 1988]. His Requirements Maturity Index (RMI) metric is related to rate of change of requirements. The RMI is an indirect measure that relies on two primitives (or direct measures) R_T and R_C. R_T is the total number of requirements in the current release. R_C is the number of requirements changes, i.e. added, deleted or modified requirements. The equation below defines RMI (Equation 3)

$$RMI = \frac{R_T - R_C}{R_T}$$

Equation 3 Requirements Maturity Index

A mature set of requirements will have a RMI = 1. To demonstrate the use of this maturity index it has been applied to data from the automotive sensor case study (Chapter 5) traceability system. The data is at a finer level of granularity compared to Felici's work, as he was working at the level of software releases rather than individual requirements. Looking at the RMI for this data, it is possible to observe the change in maturity of the requirements as the project progressed (Figure 10-1).

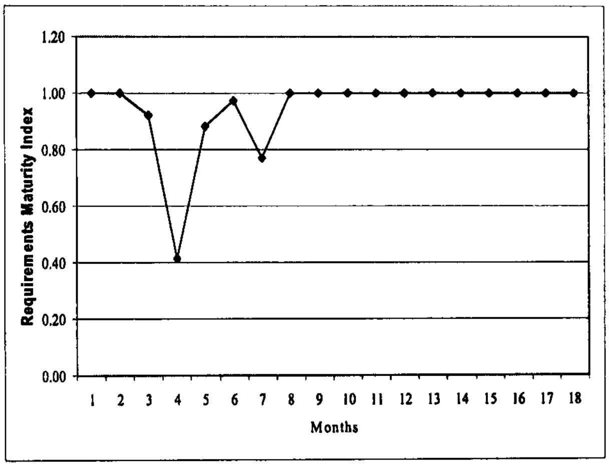


Figure 10-1 Requirements Maturity Index

In Figure 10-1, there are two dips. The first occurs in Month 4 and the second, smaller dip occurs in Month 7. This can be compared with the requirements activity shown in Figure 10-2, and with the project history; in Month 3 the specification was issued and in Month 6 the requirements were reviewed. Both events resulted in reworking of the requirements and hence a temporary fall in the RMI.

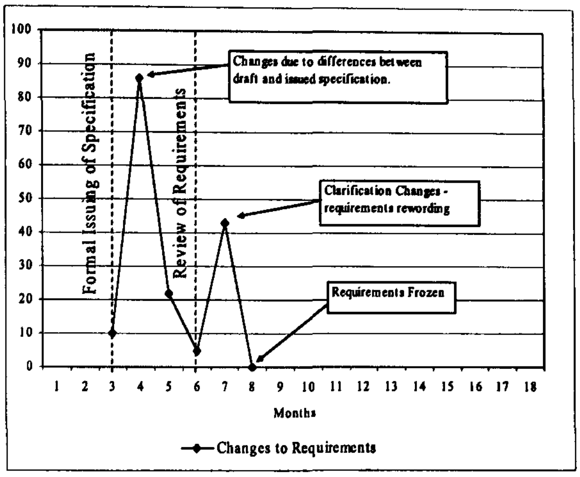


Figure 10-2 Requirements Activity

The TDC traceability structures provide these primitives for the solution artefacts. Therefore, the maturity of solution artefacts (Solution Maturity Index) can be determined by the equation below (Equation 4)

$$SMI = \frac{S_T - S_C}{S_T}$$

Equation 4 Solution Maturity Index

S_T is the total number of solution artefacts in the current release. S_C is the number of changes made to the solution artefacts, i.e. added, deleted or modified requirements. Therefore, as demonstrated above, the traceability data will allow the project manager to determine the maturity of a set of solution artefacts.

10.6.3 Artefact Traceability - Arity and Distribution

The number and distribution of traceability links can indication of the state of the evolution of the solution[Hull et al. 2004], as follows:

Solution Artefact Satisfaction Traceability

With the exception of the development of a prototype, the distribution of solution satisfaction traceability links gives a guide to the state of the evolution of the solution. Solution artefacts that satisfy above average number of problem artefacts should be consider as candidates for further decomposition. For example, solution artefact D in Figure10-3.

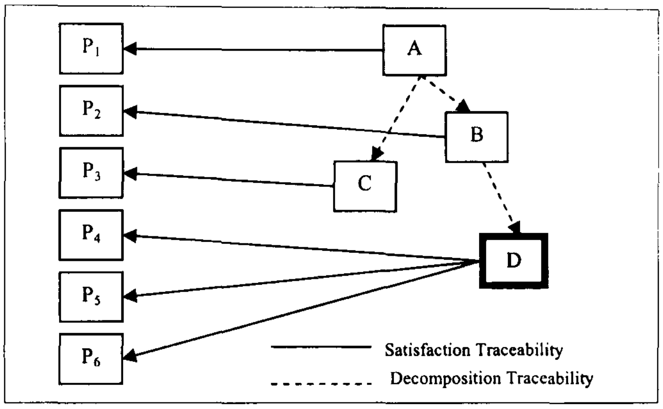


Figure 10-3 Trying to Satisfy Too Many Problem Artefacts

Problem Artefacts that are satisfied by a large number of solution artefacts, for example P_1 in Figure 10-4, should be given special consideration, as a change to such an artefact would have a large impact on the solution.

This situation can occur for non-functional requirements. For example, a requirement that defines the limits of the system's memory would be satisfied by a number of design artefacts that are required to use memory.

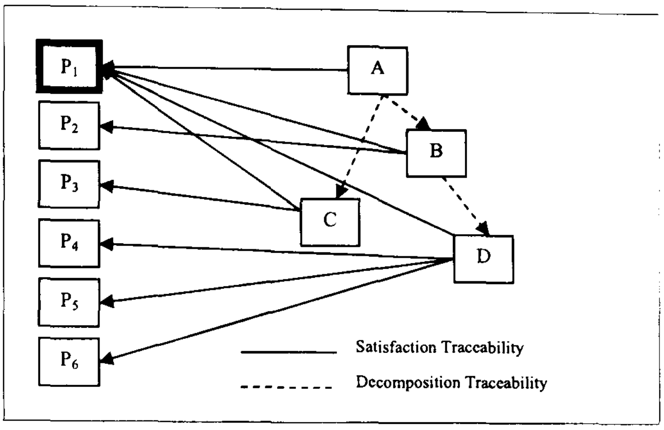


Figure 10-4 Problem Artefact Satisfied by Many Solution Artefacts

Solution Artefact Decomposition Traceability:

Solution Artefacts which have a number of parents, for example G in Figure 10-5, require attention as changes to this class of artefact can have a major impact on the rest of system. Such artefacts may perform a large number of services and therefore have low logical cohesion. G may be required to be modified so that the functionality is split between two new artefacts, G_A and G_B (Figure 10-6), therefore limiting the impact of any changes to G and improving the cohesion.

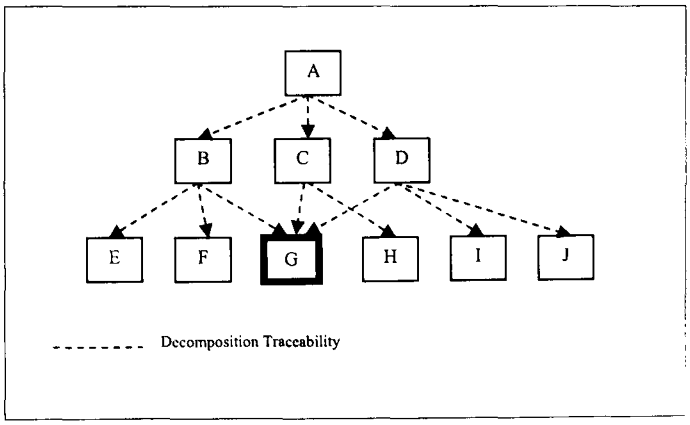


Figure 10-5 Artefact G: Too Many Parent Artefacts

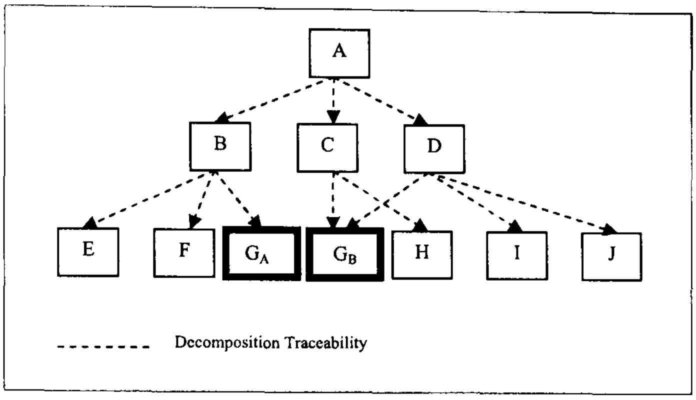


Figure 10-6 Splitting Artefact G

10.7 Coda

Conducting research on industrial development practices is difficult to organise and needs the generous support of the sponsoring companies, yet it is only by observing how we produce today's systems that we can improve the development methods of the future. The management of BAE SYSTEMS have the foresight to understand this.

At the Requirements Traceability Panel Session held at the 14th IEEE International Requirements Engineering Conference (Minneapolis/St. Paul, USA, September 11-15, 2006) a delegate asked the following question of the panel

"Our project is now required to perform traceability – which tools should we buy"

The reply from each of the panel members was the same:

"Concentrate on how your project will use the traceability data – then consider what tools you require"

It is hoped that this thesis will enable that delegate to determine how to use traceability data to benefit his project.

Appendix A Traceability Survey: Preliminary Questions

Traceability Survey: Preliminary Questions

Overview

The following questions have been devised to gain the maximum benefit from the project visits and also to aid the SIG customers in selecting a suitable project. This preliminary questionnaire is in four sections.

- The first group of questions, "***The Product***", are intended to give an overview of the product and its complexity. A large, complex project may have more traceability issues than a smaller self contained project.

- The second group of questions, "***Project Organisation***", are concerned with discovering how the people in the project are organised. The way people are organised in projects may have a bearing on traceability. For example there have been a number of well-documented examples where failures in traceability have been traced to the problems of distributed team working practices.

- The third group of questions, "***Communications***", are concerned with how the project communicates within and externally. If a project has poor communications then this could lead to information loss and thus lead to poor traceability.

- The final group of questions, "***Tools and Protocols***", are concerned with looking at what tools and protocols projects teams are using to overcome the problems related to traceability.

The Questions: *Help on how to answer them.*

Please bear in mind the following when you answer the survey questions:-

- The most difficult aspect to any survey is the writing of the questions. It is difficult to write short, concise questions which are not ambiguous. Therefore, under some questions there may be a hint or an alternative wording in italics.
- Not every question is applicable to all projects; therefore there may be some questions that can't be answered.
- Try, if possible, to give a full descriptive answer. Too much information at this stage is not a problem, for it will aid in the development of the interview questions. Don't spend too long on this questionnaire; the real questions are yet to come.
- If possible, please use a word processor to complete the questionnaire, failing that, handwritten answers on a printed version will be acceptable.
- Finally, if there are any problems, please contact me.

When the questionnaire is completed, please email or mail it to:

Paul.Arkley@ncl.ac.uk

Paul Arkley
Centre for Software Reliability
Bedson Building
Newcastle University
Newcastle upon Tyne

Telephone: 0191 222 3589

Traceability Survey: Preliminary Questions

The Product

These questions are intended to give an overview of the product and its complexity.

1] What is the product produced by the project?

(A brief description of the product: what is it?)

2] Is the product self-contained or is it a subcomponent?

(Is the product a wing or the final aircraft?)

3] Is the product for an internal or external customer?

4] Does the product employ subcomponents from external suppliers?

5] What is the current development phase of product?

(Design, Development, Production or Maintenance?)

6] What is a rough estimate of the cost of development of the product?

Traceability Survey: Preliminary Questions

Project Organisation

The following questions relate to discovering how the project staff are organised.

1] Are project staff dedicated to one project or do staff report to a number of projects?

2] How many people work on the project?

(Rough estimate)

3] How many work area teams is the project divided into?

(Would be possible to include a project organisation chart?)

4] Are all the teams on the same (physical) site?

(Or the teams distributed)

5] Are the project staff all employed by the same company?

(BAE SYSTEMS, EDAS, Airbus)

Traceability Survey: Preliminary Questions

Communications

These questions are concerned with how the project communicates within and externally.

1] Does the project use email?

2] Do teams produce progress reports?

(Do teams write a weekly progress report?)

3] Are progress reports visible throughout the project?

4] How do staff members report problems that require documentation or code changes to their peers or immediate management?

(Verbally, informally via email, formally in written report?)

5] How are staff members told of changes to documentation or code?

(Verbally, informally via email, formally in written report?)

6] Do team members have visibility of outstanding changes, bugs or problems?

(Can a team member query a tool or file systems to find out what problems exist?)

7] How many official languages are spoken within the project?

(English, French, Italian etc)

Traceability Survey: Preliminary Questions

Tools and Protocols

These questions are concerned with looking at what tools and protocols, projects teams are using to overcome the problems related to traceability.

1] Does the project employ any design or integrated development tools?
(Tools such as Teamwork?)

2] What is the main tool for documentation?
(MSWord, WordPerfect?)

3] How does the project version control its documentation and source code?
(Does the project use a tool such a SCCS?)

4] How does the project record changes to documentation and source code?
(By adding comments to the original document or by recording comments in a version control tool?)

5] How does the project formally record outstanding bugs or problems?
(Does the project record the problems in a database, development tool or in a paper based system?)

Thank you for your input

Appendix B TDC Database Schema

Artefact

The Artefact structure can be implemented by relational tables 6 to 10.

Artefact							
Artefact UID#	Description	Location	Application	Development Status {Not Agreed |Agreed| Deferred}	Change UID#	Authority (Stakeholder UID#)	Implementer (Stakeholder UID#)

Table 6 Artefact

Stakeholder				
Stakeholder UID#	Name	Email	Tel	Address

Table 7 Stakeholder

Query				
Query UID#	Artefact UID#	Stakeholder UID#	Query Text	Reply UID#

Table 8 Query

Query Reply			
Reply UID#	Query UID #	Stakeholder UID#	Reply Text

Table 9 Query Reply

Change						
Change UID#	Affected Artefact (Artefact UID#)	Description	Type {Copy|Add| Remove|Alter}	Proposed By (Stakeholder UID #)	Authority (Stakeholder UID #)	Implementer (Stakeholder UID #)

Table 10 Change

Artefact Satisfaction

The Artefact Satisfaction structure can be implemented by relational tables 11 to 12.

Satisfaction			
Satisfaction UID#	Problem Artefact UID#	Solution Artefact UID#	Satisfaction Argument UID#

Table 11 Satisfaction

Satisfaction Argument	
Satisfaction Argument UID#	Text

Table 12 Satisfaction Argument

Artefact Decomposition

The Artefact Decomposition structure can be implemented by relational tables 13 to 15

Decomposition		
Parent Artefact UID #	Child Artefact UID #	Domain Information Text

Table 13 Decomposition

Interface		
Interface UID #	Artefact UID #	Description

Table 14 Interface

Attribute				
Attribute UID #	Interface UID #	Name	Type	Constraint

Table 15 Attribute

Artefact Validation

The Artefact Validation structure can be implemented by relational tables 16 to 18

Validation Method			
Artefact UID	Description	Test UID #	Tester (Stakeholder UID #)

Table 16 Validation Method

Test		
Test UID#	Description	Results UID #

Table 17 Test

Results		
Result UID#	Description	Location

Table 18 Results

Appendix C Example Accipiter Queries

Information Queries

The following are examples of information queries, which would be performed by the BAC software team (down stream team) while assessing the suitability of the requirements (problem artefacts).

Query

What is requirement 10.5?

Possible Implementation

Select Requirement.Description from Requirement where Requirement.UID='10.5';

Returned Data

"The Mission Computer will read and validate each waypoint from the tape. Writing the contents of each waypoint to FlightPlan.dat data file (For the format of FlightPlan.dat refer to Appendix G: Data Formats"

Query

Who is the authority for Requirement 10.5?

Possible Implementation

*Select *from Stakeholder where Stakeholder.UID= (Select Requirement.Authority from Requirement where Requirement.UID='10.5');*

Returned Data

"Requirements Analyst
James Walker
James.Walker@BAC.com
01904433384
BAC Aerodrome, Cumbria."

Query

Who is the implementer of Requirement 10.5?

Possible Implementation

*Select *from Stakeholder where Stakeholder.UID= (Select Requirement.Implementer from Requirement where Requirement.UID='10.5');*

Returned Data

"Requirements Analyst
Andrew Adams
Andrew.Adams@BAC.com
01904433385
BAC Aerodrome, Cumbria."

Dialog Queries

The following are examples of dialog queries, which would be performed by the BAC software team (asking questions) and the requirements team (replying to the raised questions)

Query

Raise a query on requirement 10.5: (Insert a question in the Query Table)

Possible Implementation

Insert Into Query (Query_UID,_Artefact_UID, Stakeholder_UID,Query_Text) Values ('QUID124', '10.6', 'Andrew Adams', "Where is the Waypoint syntax defined?";

Query

Are there any outstanding queries on the requirements written by Andrew Armstrong?

Possible Implementation

Select Query_UID, Query_Text, "Raised by", Stakeholder_UID from Query whereQuery.Artefact_UID=(Select Artefact_UID from Artefact where Implemter_UID='Andrew Armstrong')

Returned Data

" Where is the Waypoint syntax defined? Raised by Andrew Adams"

Query

Reply to query on requirement 10.5?: (Insert a reply in the Query Reply Table)

Possible Implementation

Insert Into Query_Reply (Reply_UID, Query_UID, Stakeholder_UID,Reply_Text) Values ('RUID145','Responding to QUID124', 'Andrew Armstrong',"The Waypoint syntax is defined in Appendix H";

Query

What is the reply to QUID124?

Possible Implementation

Select Reply_Text, "reply by", Stakeholder_UID from Query_Reply where Query_Reply.Query_UID='124')

Returned Data

"The Waypoint syntax is defined in Appendix H reply by Andrew Armstrong"

Status Queries.

The following are examples of artefact status queries, which would be performed during Problem Discourse stage.

Query

What is the development status of requirement 96?

Possible Implementation

Select Requiremen.Development_Status from Requirement where Requirement.UID='10.5';

Returned Data

Not Agreed

Query

Change the development status of requirement 10.5 to "Agreed".

Possible Implementation

Update Artefact Set Development_Status ='Agreed' where Artefact.Artefact_UID='10.5';

Satisfaction Queries.

The following are examples of artefact satisfaction queries.

10.13	Description: On the successful insertion the Mission Computer will display – "PDC Inserted"

Query

Which design artefacts satisfy requirement 10.13?

Possible Implementation

Select Description, Location, UID,Application from Design where Design.UID = (Select Design_UID from Design_Satisfaction where Design_Satisfaction.Requirement_UID ="10.13")

Returned Data

UID#:D1.4
Description: Tape Package
Location //Acc/300/Des/Mission_Pack_UML.uxf
Application: Umlet
Status: Not Agreed

The same process would be repeated to discover which code modules satisfied the design artefact D1.4.

Query

Which code artefacts satisfy design artefact D1.4?

Possible Implementation

Select Description, Location, UID,Application from Code where Code.UID = (Select Code_UID from Code_Satisfaction where Code_Satisfaction.Design_UID ="D1.4")

Returned Data

ID#: C1.6
Description: Tape Interface Package
Location//Acc/300/Code/TapePackage.c
Application: Text editor
Status: Not Agreed

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