CRANFIELD UNIVERSITY

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Cost Impact Analysis for Requirements Management

SCHOOL OF APPLIED SCIENCES

PhD THESIS

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PATRICK ADEMOLA ODUGUWA

Cost Impact Analysis for Requirements Management

Supervisor: Professor Rajkumar Roy

October 2006

This thesis is submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy

To the memories of my mother,

May your soul rest in perfect peace

'Thank you for all your love and support mum'

Declaration

Except where otherwise stated, this thesis is the result of my own research and does not include the outcome of work done in collaboration.

This thesis has not been submitted in whole or in part for consideration for any other degree qualification at this or any other institute of learning.

Patrick Ademola Oduguwa
Manufacturing
Cranfield University
October 2006

Abstract

Competition and the associated challenges in the automotive industry are increasing. Products are becoming more complex to satisfy growing needs of the consumers and products need to be cheaper and produced quicker. The automotive industry is responding to these challenges, by developing products within collaborative and extended enterprises across diverse geographical location. New customer requirements imply high frequency changes to the initial design requirements.

Current unstructured approaches are not robust to deal with the volume and complexity of the nature of product changes in this environment. The aim of this research is to develop two methodologies, one for requirements extraction methodology (REXTRAM) and the second cost impact analysis methodology (CIAM) within the automotive industry. The research was conducted in a collaborative development environment between automotive Original Equipment Manufacturers and Tier 1 Suppliers.

The thesis has proposed two novel methodologies. The first methodology (REXTRAM) extracts relevant data from product design documents and industrial domain experts. REXTRAM generates as output a repository of requirements, design parameters and their constraints. The second methodology (CIAM) identifies two types of changes (constraints changing on requirements and constraints changing on design parameters). CIAM combines matrixes and business (cost and time) driver rules to determine incurred (delta) cost of requirement changes. The matrixes exhibit three types of relationships: requirements to requirements; requirements to design parameters and design parameters to design parameters relationships.

Case study approach and independent expert are used to illustrate the application and the capability of both methodologies. In this way this research proposes a tested and validated set of methodologies for the extraction of relevant data and the cost impact analysis of requirement changes and its challenges. The resultant methodologies have widespread application in the context of complex mechanical designs. The research also identifies future research directions in the relevant areas.

Acknowledgements

I would like to express my deep gratitude to the ALMIGHTY GOD for the wonderful gift of life.

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It has been a great pleasure working with my colleagues in the Centre for Decision Engineering at Cranfield University. It is not possible to list their entire names, but particular thanks go to Pius Achanga, Dr Benjamin Adesola, Dr Ashutosh Tiwari, Dr Clive Kerr, Dr Paul Blackwell, Gokop Goteng and Mr Jeevan Sagoo. Thanks also to all the staff of the Department of Enterprise Integration for their support.

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Finally, this work would not have been completed without the most precious people in my life. Their everyday patience, love and care, is the motivating force for all my accomplishments. I express my deepest love to my wife Mrs Oritsema Oduguwa and to my children Patricia, Davina, Dorothy and Vanessa.

List of Publications

Oduguwa, P. A., Roy, R. and Sackett, P. J. (2004) Impact of Requirement Changes on Automotive Product Development In *The 2nd International Conference on Manufacturing Research (ICMR 2004) - Encouraging Applied Research in Industry,* Sheffield Hallam University, United Kingdom, pp. 168-173 1-84387-088-6.

Oduguwa, P., Roy, R. and Sackett, P. (2005) "A Rule Based Cost Estimating Approach for Design Requirement Changes". *The 5th Joint ISPA/SCEA International Conference and Educational Workshop.* Denver, Colorado, USA, 14-17 June

Roy, R., Kerr, C., Oduguwa, P., Makri, C. and Sackett, P. (2005) "Design Requirements Management: A New Perspective". *Proceedings of the 15th International CIRP Design Seminar.* Shanghai, China, May 22 - 16 pp. 214 - 222.

Oduguwa, P., Roy, R., & Sackett, P. J., (2006) "Cost impact analysis of requirement changes in the automotive industry: a case study", Accepted for Journal of Engineering Manufacture, Part B, IMechE, ISSN 0954-4054.

Oduguwa, P., Roy, R., & Sackett, P. J., (2006) "Developing a Methodology for the Extraction of Design Requirements and Design Parameters". Submitted to *International Journal of Manufacturing and Technology Management.*

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Acronyms

ABC	Activity Based Costing
AD	Axiomatic Design
AFDA	Application for Drawing Acceptance
BOM	Bill of Materials
C	Constraints
CIAM	Cost Impact Analysis Methodology
CM	Congestion Management
CN	Change Notification
CNM	Commercial Network Model
CS	Cooling System
CVE	Collaborative Virtual Environment
DCC	Design Change Control
DN	Design Note
DRCM	Design Requirements Change Managemt
DSM	Design Structure Matrix
DP	Design Parameters
e-RM	Electronics Requirement Management
ECM	Enterprise Cost Management
ECR	Engineering Change Request
EPSRC	Engineering and Physical Sciences Research Council

FBC	Feature Based Costing
FRD	Fax Recipt Document
IDEF	Integrated Definition
IPT	Integrated Product Team
JCI	Johnson Control International
JLR	Jaguar Land Rover
NCS	National Child Study
NDE	Nissan Design Europe
NMUK	Nissan Motor Manufacturing (UK) Ltd
NTCE	Nissan Technology Centre Europe
OEM	Original Equipment Manufacturer
PDT	Product Development Team
PLM	Product Lifecycle Management
POI	Point of Impact
QA	Quality Assurance
QAF	Quotation Analysis Form
R	Requirements
R&C	Requirements and Constraints
REXTRAM	Relevant Data Extraction Methodology
RFQ	Request for Quotation
SDT	Simultaneous Development Team

SMMT	Society of Motor Manufacturers and Traders
SOP	Start of Production
SOW	Statement of Work
ST	Specification Tender
UGS	UniGraphics Solutions
UML	Unified Modelling Language
VB	Visual Basic
VCA	Vehicle Certification Authority

1 INTRODUCTION

Managing design requirement changes is time-consuming and difficult within a single organisation. This becomes more challenging if the product definition is performed across company borders and in an environment of continuous development. Requirements management and reliable cost estimation for requirement changes are increasingly necessary and important tasks for original equipment manufacturers (OEM) and their suppliers in the design and manufacturing industry. The complex and demanding nature of consumer requirements has led to a radical shift in the thought process of some leading organisations with regards to cost estimation of requirement changes (Oduguwa *et al.*, 2004). The ability of companies to better manage changes effectively during product development can decrease cost, shorten development time and produce higher quality products (Rouibah and Caskey, 2003).

Most product development involves the evolution of an initial design (Sudjianto and Otto, 2001, Ho and Li, 1997, Becker and Wang, 2003) during the product development phase. The number of requirement changes becomes smaller as product development evolves. However, the cost and complexity increases as the changes made later in the development time have the potential to impact more clearly defined systems within a product, such as a vehicle. Even if this evolution process is controlled, the cost impacts can be both significant and difficult to predict.

Once product life cycle cost estimates have been made, any additional changes to the product definition will incur more cost. These changes have to be managed correctly to reduce both ripple effect propagation and manufacturing cost. A change from the OEM can filter through the extended enterprise. For example, Figure 1-1 depicts an extended enterprise approach adopted by automotive companies. A change proposed by the OEM ripples to the Tier 1 Supplier; this will in turn ripple to Tier 2 Suppliers, and so on. Ripple effects can also be translated from one system to another system i.e. a change rippling from one Tier 1 Supplier to another Tier 1 Supplier. The profit margin reduces every time a change is made to the product definition.

Therefore the research aim is as follows:

To develop a cost impact analysis methodology for design requirement change management of mechanical components within the automotive industry.

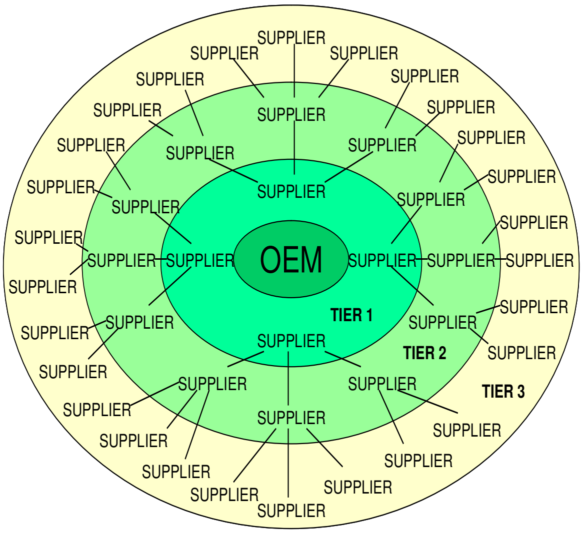


Figure 1-1: Automotive Extended Enterprise

Automotive products are modular (Marotz, 2003), these modules are referred to as automotive systems. Figure 1-2 illustrates a typical decomposition of a vehicle into a finite number of systems. In most cases, these systems are wholly supplied by one or more Tier 1 Suppliers. For example, the seating system is supplied by one Tier 1 Supplier, while others are supplied by multiple suppliers. For example, four Tier 1 Suppliers supply the cooling system. The cooling system is made-up of five subsystems: the expansion tank, the radiator, the hoses, water pump and the fan, each of which is supplied by a different supplier.

Estimating the cost of a requirement change accurately and quickly requires a generic methodology that is scalable, extendible, portable, visible, and easy to use. Requirements in the context of this research are 'what the product must do'. An OEM product specification document reflects different product views, including a functional and a physical component approach of representing a product instance. From a functional point of view, products are described in terms of what the product is intended to do (Makri *et al.*, 2004).

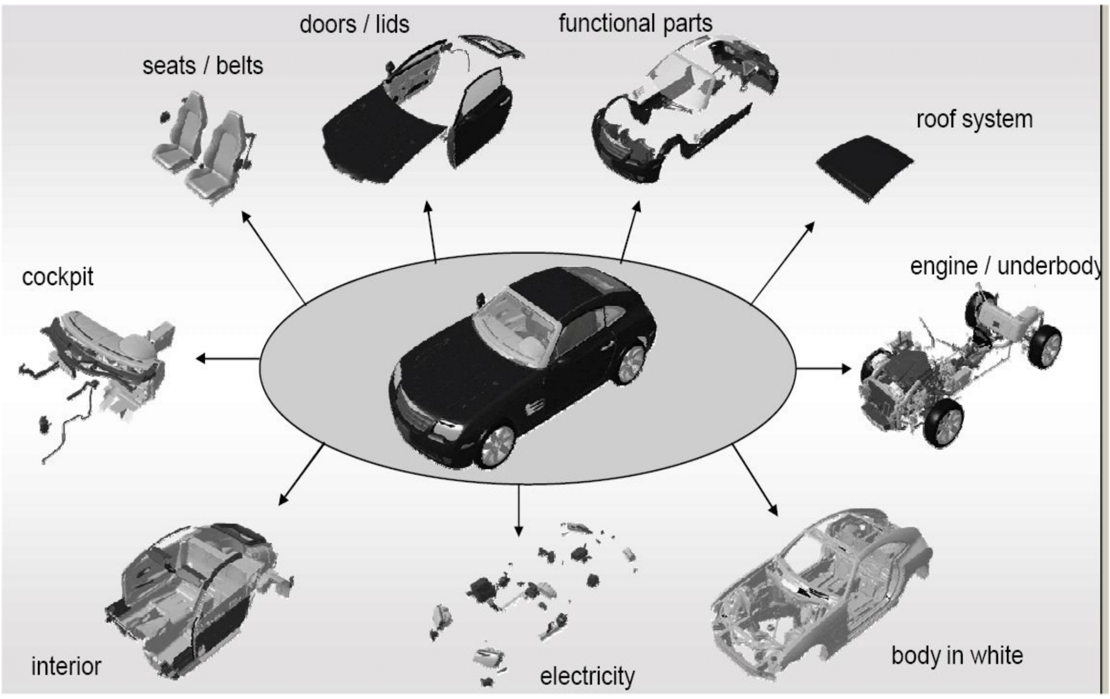


Figure 1-2: Car Systems

This chapter is organised as follows: Section 1.1 introduces the context of the research. Section 1.2 discusses the e-RM project, the motivation of this research, which led to the development of the Cost Impact Analysis Methodology. Section 1.3 introduces the collaborating organisations and outlines the importance of the research project to the sponsor organisations. Section 1.4 discusses requirements management in the automotive industry. Section 1.5 presents an overview of cost estimation in the automotive industry. Section 1.6 discusses why requirements management and cost engineering are important for the automotive industry. Section 1.7 outlines the theses structure.

1.1 Research Context

The scope of design requirement changes addressed in this thesis is at the early design phase. Most product development involves the evolution of an initial design (Sudjianto and Otto, 2001, Ho and Li, 1997, Becker and Wang, 2003). Even if this takes the form of controlled evolution the cost impacts can be significant and hard to predict during the product development phase as illustrated in Figure 1-3.

A methodology is required for the cost estimation of evolutionary product requirement changes during an extended product life cycle. The application zone of the methodology will be the phase following a specification design document of the component and an initial cost estimate being accepted (Figure 1-3).

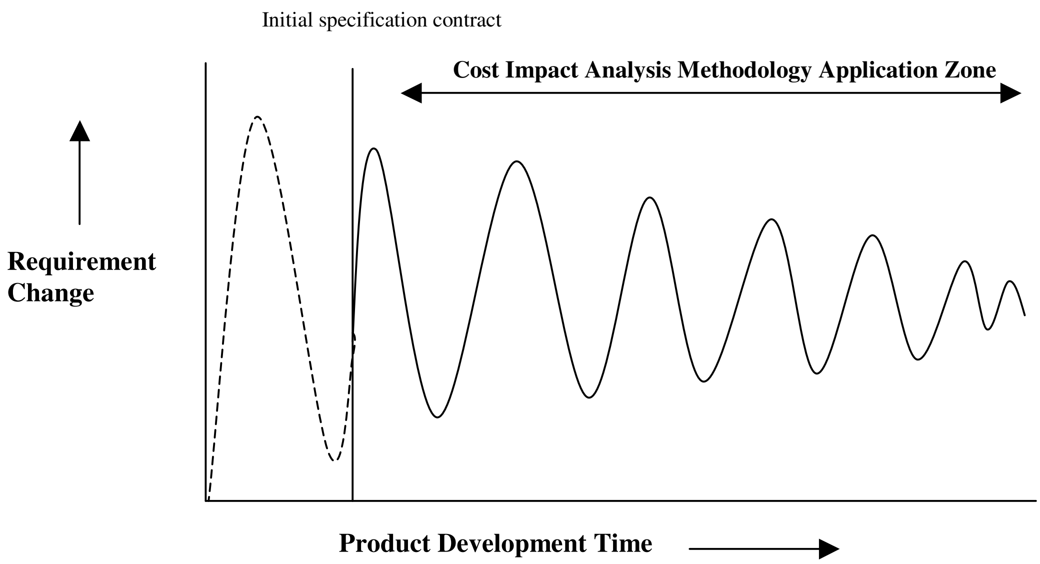


Figure 1-3: Evolutionary Requirement Change and Time Correlation

1.2 Research Motivation

The research was initiated for three years as part of the Integrated Requirements Management for Digital Electronic Product Development (e-RM). The research was funded by the Engineering and Physical Sciences Research Council (EPSRC). The project aimed to improve an organisation's capability to develop, capture and manage requirements and constraints in the Extended Enterprise. The benefit to industry is the visibility of requirements and constraints during design and manufacturing, together with the cost impact of any design requirements change.

Automotive OEMs are currently working with their major suppliers to align and improve their product design and development process. According to the director of business development at an OEM Company, "evolving technological and process alignment is key for better supply chain integration. Design requirements management is a key issue in this digital process and the timing of the e-RM project is very appropriate for the industry”.

This project is a natural follow on from Nissan’s current activities and successful collaborations with Cranfield University, namely the Cogent-Next Steps/e-Cogent and Cogent programmes. Additionally, the Foresight Vehicle has recognised the increasing delegation of design responsibility from the OEMs to their suppliers. The project is also in line with the Foresight Vehicle objectives (Roy et al., 2002). This is due to the fact that the e-RM project addresses issue of great importance to the Foresight Vehicle and the former IMI Road Transport programme.

This research outcome will lead to a cost impact analysis for engineering requirement change. The research findings and outputs will also lead to a “Best Practice” for the automotive industry. The experiences and knowledge gained from the e-RM project will be shared with the mechanical design community and other engineering industries including aerospace industry. The research result will help companies to manage their requirements activities more effectively and efficiently.

1.2.1 e-RM Project

A key benefit of requirements management is the establishment of traceability from the original need and product specification through the lifecycle to the completed deliverables and acceptance criteria (Thomson, 2001). Engineering design require a large amount of information (Roy *et al.*, 2004d). Channelling the information to the correct recipient at the right time is a challenging task, especially when dealing with the requirements of a complex product. Zhang *et al.,* 2003 suggested that a web-based product information sharing system is a foundation tool for collaborative product development. The e-RM project facilitates a system to achieve improvements in the automotive product development process by the e-enabling of requirements management using a collaborative web-based architecture (Roy et al., 2004d).

The e-RM enabled platform is the next evolutionary step in digital product development for the automotive extended enterprise. The aim of e-RM project is to provide a fluid and seamless tool for the handling and communication of product requirements thus allowing their greater availability, distribution and sharing in the extended enterprise. The e-RM project has three main tasks:

1. the application of ontology for representing the design requirements (Kerr *et al.*, 2004c)
2. an electronic workflow to share the ontologically structured design requirements within an OEM and then through the extended enterprise to suppliers (Makri *et al.*, 2004)
3. a cost impact methodology for the analysis of requirements changes (Oduguwa *et al.*, 2004)

The third task forms the basis for the research in this thesis, which will focus on complex mechanical systems within the automotive industry.

1.2.2 The e-RM Framework

To achieve the benefits of electronic requirements management, a framework has been developed to realise the e-RM platform for exploitation in the automotive industry. Figure 1-4 illustrates an overview of the web-based integration framework for e-enabling requirements management in the extended enterprise. At the centre of the framework is the vehicle manufacturer who houses the 'global' requirements management system. This system is the single source of product requirements information for a vehicle programme or project and based on an ontologically structured 'global' requirements repository. The structuring and documentation of the requirements is in a common standardised electronic format. The vehicle manufacturer allows their suppliers authorised access limited to the modules or subsystems to which they are responsible for producing. The suppliers have a portion of these requirements data housed in their own 'local' clients for internal dissemination in their respective organisations. A secure web-based front-end is used by both the OEM and suppliers for the uploading, browsing and downloading of the product requirements for specific parts.

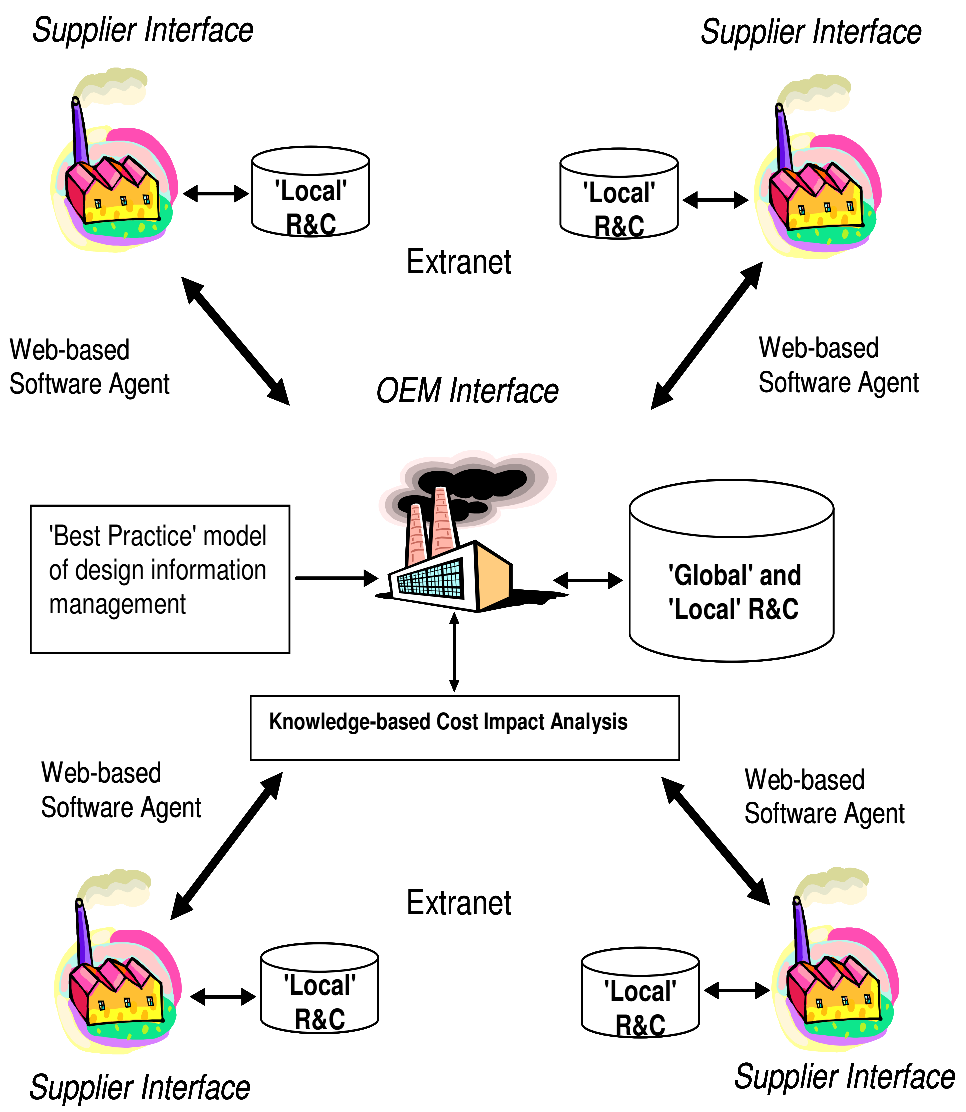


Figure 1-4: Proposed e-RM Framework

Using the requirements repository as the single source of information, requirement changes are automatically updated through the extended enterprise to the affected suppliers. This automatic provisioning of only the actual updated change, as opposed to the whole specification, will reduce the manual collection effort and workload using a front-end reporting tool. An automated set of business process procedures will control the aspects of creating and maintaining agreement of the requirements, together with the associated decision-making and communication in the extended enterprise. Instead of individual changes being issued serially, the requirements processing capabilities of the e-RM system will highlight how several changes can be concurrently compiled and released as single combined issue.

1.3 The Collaborating Organisations

This section explores the background, the business environment of the collaborating organisations and discusses the motivations that led to the initiation of the Doctor of Philosophy (PhD) research. This research was carried out in collaboration with Nissan Technology Centre Europe (NTCE), Johnson Control International (JCI), UGS, and Society of Motor Manufacturing Traders (SMMT). Jaguar Land Rover (JLR) and Visteon further evaluated the findings and conclusions of this research.

1.3.1 Nissan Technology Centre Europe (NTCE)

Nissan is one of the world's largest car manufacturers with manufacturing locations globally. Its first ever car was made in 1914 and the company now have various design locations worldwide. Nissan is engaged in corporate activities on a worldwide scale, operating 20 manufacturing companies in 16 countries around the world with a combined annual production volume of approximately 2.6 million units, and marketing Nissan vehicles in 191 countries worldwide. For example, within the European market design work takes place in the London-based Nissan Design Europe (NDE) centre while development work is carried out at the Nissan Technical Centre Europe (NTCE) in Bedfordshire. Production is carried out in the Nissan Motor Manufacturing (UK) Ltd (NMUK), in Sunderland.

Nissan cars are developed through active collaboration among the company's design, engineering, production and other divisions with major automotive Tier 1 Suppliers. Nissan has a large supply base, an earlier project (Cogent) between Nissan and Cranfield University collaborated with 35 of Nissan's Tier 1 Suppliers. In addition to its automotive operations, Nissan has diversified into a broad spectrum of business fields, ranging from aerospace equipment, particularly the development of rockets, to marine equipment, including motorboats and the management of marinas.

1.3.2 Johnson Controls Inc. (JCI)

Johnson Controls was founded in 1885 by Professor Warren Johnson to manufacture his invention, the electric room thermostat. Johnson Controls is now a multi-billion dollar corporation, with worldwide leadership in two businesses: automotive systems and building controls.

JCI is the world's largest independent supplier of automotive interior systems such as seats, electronics, instrument panels, overhead, floor consoles, doors, and cargo management. JCI has approximately 123,000 employees in over 500 locations worldwide. Customers include BMW, DaimlerChrysler, Ford Motor Company, General Motors, Honda, Mazda, Mitsubishi, Nissan, Renault, Rover, Toyota and Volkswagen.

1.3.3 UniGraphics Solution (UGS-PLM)

Unigraphics formally known as Electronics Data Solutions (EDS) is a market leader in the Product Lifecycle Management (PLM) industry. Unigraphics PLM is state-of-the-art, knowledge-driven, standardised and open-system. This represents the PLM industry’s most comprehensive, flexible and innovative suite of requirements management tools. With more than 3 million licenses in use and 42,000 clients worldwide, UGS solutions have been helping companies accelerate time to market, improve quality, and increase revenue for almost four decades.

1.3.4 Society of Motor Manufacturers and Traders (SMMT)

Society of Motor Manufacturers and Traders (SMMT) exists to provide services and support for the automotive industry. Since 1902, SMMT has provided a focus to reflect its ever-changing needs and interests. Automotive organisations however, share one common link, through membership of SMMT. The most significant link is the representation to government at home and abroad on key industry issues. National and international events are exhibited to provide advice on reliable data and practical advice on the automotive industry.

1.4 Introduction to Requirements Management

Requirements management starts with the definition of requirements, constraints and design parameters. This continues through the project, culminating in the comparison of the product against the defined requirements. Requirements are the statement of the customer's need, translated into an engineering definition and subsequently into a delivered product. Crucial to any supplier is the definition of a set of precise, unambiguous, consistent, comprehensive and detailed requirements to which they will be contractually bound.

Most requirements are defined during the early stages of product development. Requirements evolve throughout the life cycle of the product. This is to reflect the changing needs and constraints imposed by the stakeholders (the customer organisation and the operational environment). Changes to a single requirement or a constraint (non-functional requirement) may ripple through a system and affect other requirements, constraints and organisational goals. When requirements management is properly performed, it reduces the time that engineers spend finding the information that they need to do their job.

The requirements management process ensures that what the customer wants (i.e. requirements) is known and that the solution efficiently meets these requirements (Leinonen and Huovila, 2001). Requirements engineering represents up-front work, for which benefit does not appear until later (Stevens and Martin, 1999). Requirements Management involves activities such as specification, validation and management. Thereby, eliminating version mix-ups and reducing human errors. There are several types of requirements: functional requirements, legislative requirements, customer requirements, safety, performance, comfort and convenience.

The management of the requirements and constraints for mechanical design is based on expert knowledge. This involves an ad-hoc process, and therefore is time consuming and expensive. There is a lack of effective tools and techniques for the requirement and constraint management within a supply chain. Worldwide, manufacturing industries with high 'product complexity and market uncertainty', such as the automotive industry, are typically out-sourcing 70%-85% of design activities to their suppliers (external and internal) (Schweitzer, 2003). Classically, the individual supplier performs a part of the whole design and optimises it locally. The individual design entities lose perspective of the whole product design and these multiple isolated optimisations are not effective from a total business viewpoint.

Automotive product development in general requires highly intensive engineering effort. This usually involves many companies collaborating in an extended enterprise. Automotive OEMs are increasingly recognising the benefits of involving their suppliers in the product design process. Product specification plays a central role in guiding the OEM-supplier relationship. While the OEM prepares a specification document, it does not usually take into consideration the requirements of the suppliers in fulfilling the product.

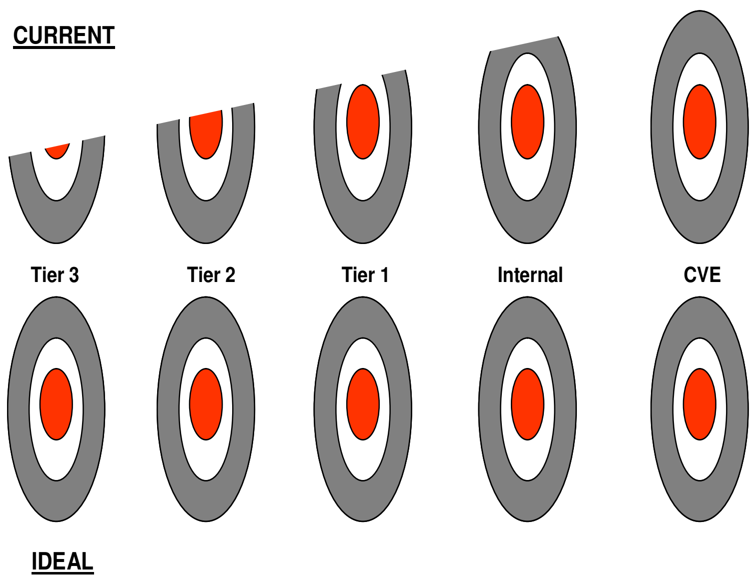


Figure 1-5: Visibility of Target

The visibility of target reduces as the project proceeds along the extended enterprise, as illustrated in Figure 1-5. However, if the product manufacturing cost can be estimated during the design stage, designers can modify a design to attain proper performance and estimate a reasonable cost at an early stage of the product development process. An ideal situation exists when all stakeholders along the extended enterprise have equal visibility of the target as shown in Figure 1-5. It is essential under these changing conditions that the process of developing cost models is able to remain responsive to user requirements and to remain effective in terms of the resources required to generate these models.

The determination of manufacturing cost is affected by shape complexity and product precision tooling processes. Customer requirements, market expectations, selling price perceived quality are all factor that contributes to upstream requirement. Upstream requirements are generated by the OEM. The supplier in collaboration with OEM agrees on a set of down-stream requirements. These requirements are layout, packaging, detailed design, technical expertise, specifications and investments. Both upstream and down-stream requirements determine the product target, which are manifested as weight, cost, tooling as shown in Figure 1-6. If these data can be obtained and considered during the design stage, estimating manufacturing cost during the early product development stage will become a feasible task.

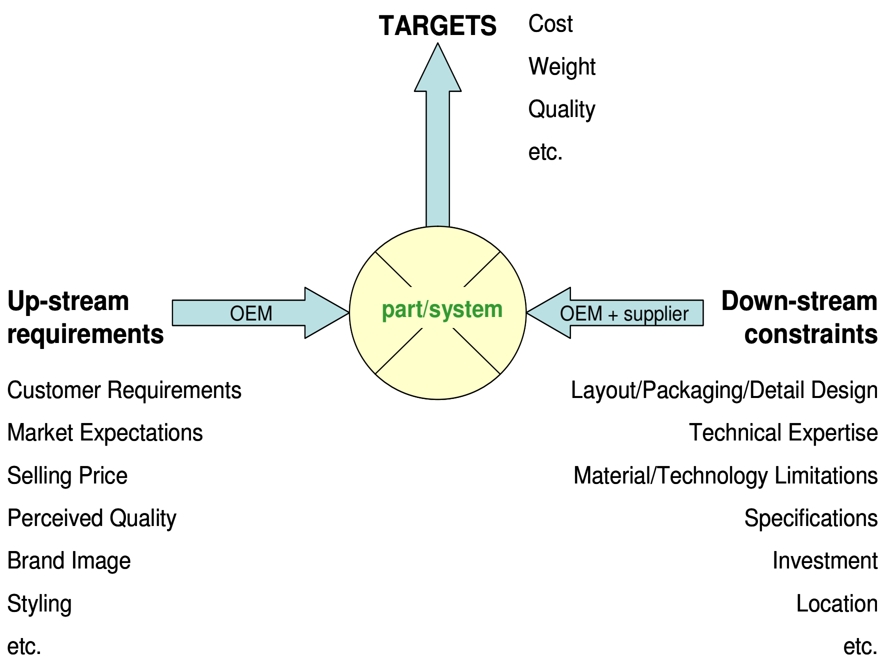


Figure 1-6: Target Variation Due to Requirement Changes

1.5 Introduction to Cost Estimation

Cost estimation can be defined as "the art of approximating a probable worth or cost of an activity based on information available at the time" (Stewart, 1991). In many engineering organisations, cost estimation is seen as a separate activity from design, which cannot be undertaken until the design characteristics have been established.

This sequential aspect is reinforced by each being carried out by different departments, sometimes responsible to different Directors.

In some industries, cost information is guarded, so that even if designers wished to cost out design alternatives, they have no access to relevant data. Indeed, it has been shown that when the design of a product is finished, although only 10% to 15% of the total cost has been spent, 80% of the costs have been committed. The more the project is advanced the less the possibility of reducing the final cost Figure 1-7, because of the high costs of modifications (Duverlie and Castelain, 1999). Therefore, the cost is a design element and so it is essential to control this parameter as early as possible.

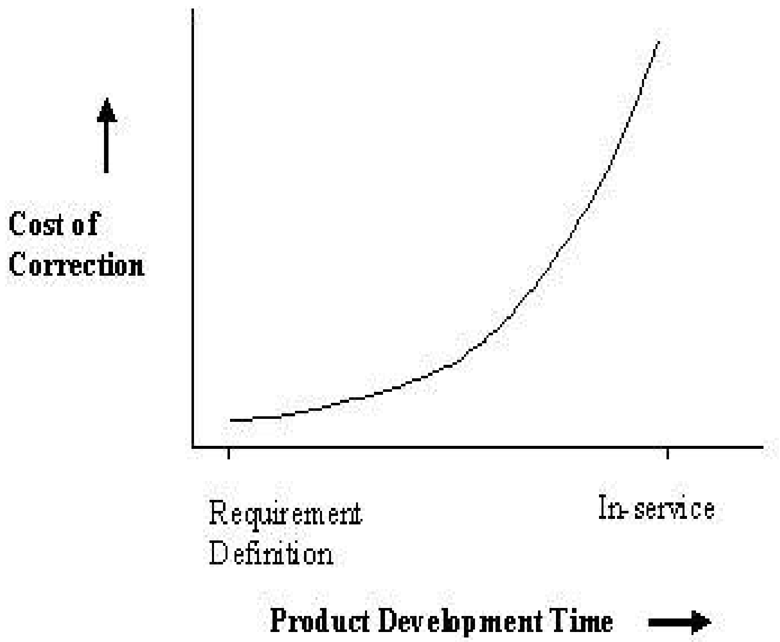


Figure 1-7: The Cost of Correcting Changes in Design Requirements

1.6 Requirements Management and Cost Estimation

Section 1.4 and section 1.5 have discussed the issues peculiar to requirement engineering and cost estimation respectively. This section addresses how requirement engineering and cost estimation affect the change management process in the automotive industry. The challenges imposed by the cost estimation of requirement changes are also valid where several departments within a company work in partnership. Integrating each supplier in the whole product design cycle can only be achieved by the effective management of the design requirements and constraints within the extended enterprise. It is widely recognised that the ability to develop, capture and manage the requirements and constraints is essential to the correct delivery of the project. Unfortunately, the methodologies to achieve these are often weak and poorly understood.

In essence, designers need visibility of both customer requirements and local constraints. The design requirements and constraints evolve during the life cycle of the design through complex negotiations between the OEM and the suppliers. It is necessary to manage this evolution of the design information and make the process more transparent. The OEM has a set of ‘global’ design requirements and constraints, while, a supplier will have ‘local’ requirements (cascaded requirements) and constraints. Local requirements and constraints are partly determined by the ‘global’ sets.

Typically, a supplier will add ‘local’ constraints for the design. It is cheaper to correct issues related to product design during the requirements development phase rather than in the downstream design activities. The definition (status) of the requirements and constraints become progressively firmer, during the product definition process. The financial impact of any change of requirements and constraints also increases with the product definition (meaning flexibility is reduced).

For any proposed change in the ‘hard’ or ‘soft’ requirements and constraints, other related requirements and constraints should be identified and any impact analysed. The status and flexibility of requirements and constraints are important feedback that the designer should consider during any impact analysis. Tracking the design information related to the requirements and constraints in complex mechanical system projects rapidly exceeds the capability of manual or semi-automated techniques.

1.7 Thesis Structure

This section describes the structure of the thesis. Figure 1-8 shows the structure. This section aims to give a 'helicopter view' of the whole thesis. The thesis begins with an introduction to the overall research and provides an insight to the collaborating organisations.

Chapter 2 provides critical review of related work in design requirement change management, cost estimation, impact analysis, product decomposition, product representation and summary of the research gap.

Chapter 3 discusses the research methodology. It also discusses the overall research methodology applied in chapter 4, chapter 5, chapter 6 and chapter 7.

Chapter 4 provides an overview of design requirement change management process in a collaborative product development environment, between an automotive OEM and a Tier 1 supplier. Requirement management tools are also discussed as well as an overview of cost estimation tools and techniques. In addition, observations of the relationship between OEM and Tier 1 supplier are provided.

Chapter 5 discusses a relevant data extraction (REXTRAM) methodology. This methodology is developed and applied on seating system case study. The extracted data are stored in a repository, which is used by cost impact analysis (CIAM) in chapter 6, to determine the incurred cost of proposed design requirement changes.

Chapter 6 documents the TO-BE (proposed solution) process, as a result of the observations in chapter 4. This methodology is developed and applied on seating system case study. The reuse of methodology components is discussed. This chapter also provides the scope of the proposed solution.

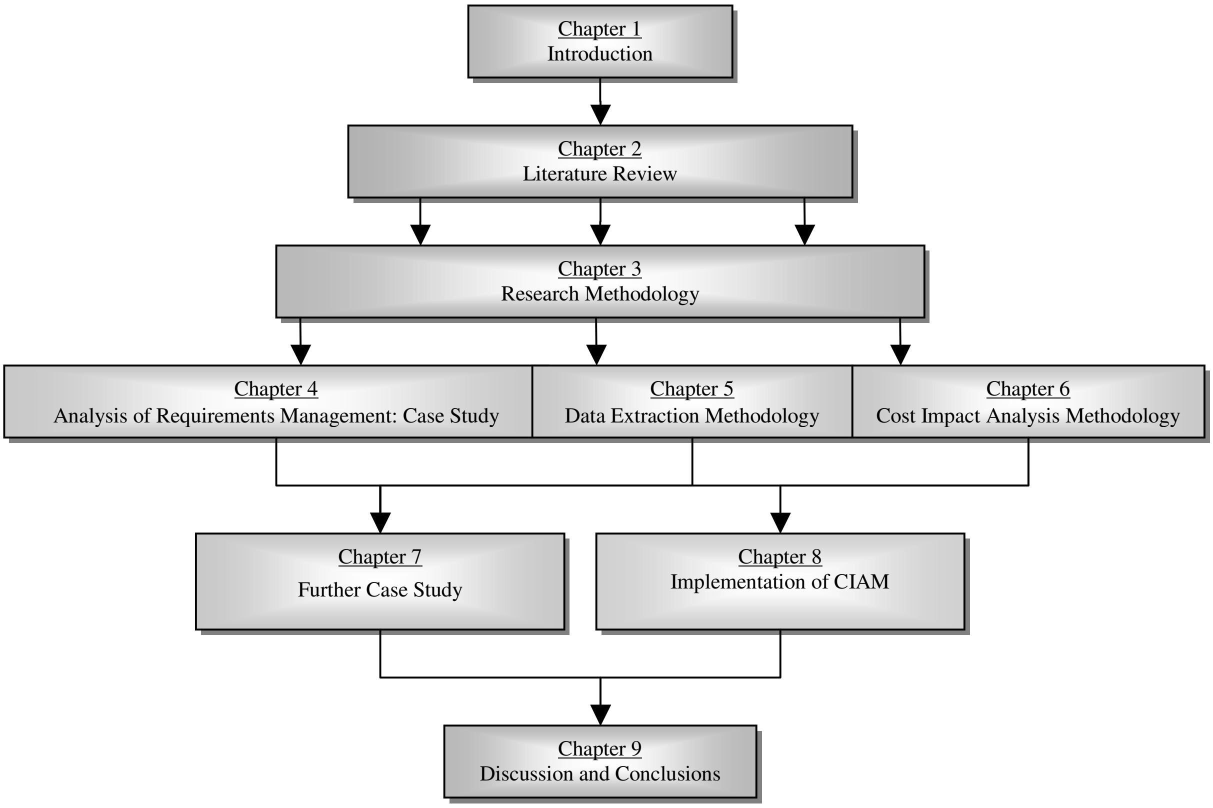


Figure 1-8: Thesis Structure

Chapter 7 applies the methodologies presented in chapter 5 and chapter 6 to another case study (cooling system). This chapter discusses the transition from one case study to another. The reusable components of the methodologies are also provided. The two case studies are compared and contrasted.

Chapter 8 provides proof of concept to automate the methodology in chapter 5. The implementation platform is VB.NET and MySQL.

Chapter 9 presents the discussion and conclusions of the research, its limitations and recommendations for future work.

2 LITERATURE REVIEW

2.1 Introduction

Chapter 1 has outlined the problem area of this research. It has discussed why the author is interested in the research and presented the main aim of the thesis. Within this chapter, the research issues are considered through a structured account from published literature. This review provides background information to support the fundamental argument of the thesis that cost impact analysis of requirement changes can be structured. Without this review, it will not be possible to adequately defend the arguments nor, will there be a need to carry out the research.

Chapter Aim:

To examine state of the art and the relationship between cost impact analysis (CIA) and design requirement change management (DRCM).

To achieve this, the literature is used to provide initial answer to the following questions:

1. What is design requirement change management?
2. What is requirements change impact analysis
3. What is cost impact analysis?
4. What methods are used for cost estimation?
5. What methods are used to establish relationships between requirements?

This chapter is organised as follows: An overview of design requirement change management is discussed in section 2.2. Requirements and constraints are defined, in relation to requirements management and requirements engineering. Requirements management tools and requirement changes are also discussed. Section 2.3 provides an overview of requirements change impact analysis, by addressing issues in the following industries; software, aerospace, construction, health and marine environments. Section 2.4 reviews cost impact analysis by distinguishing cost impact and impact analysis. Challenges in cost impact analysis and requirement change management is also provided. Section 2.5 reviews cost estimation tools and techniques, including cost drivers. Section 2.6 reviews axiomatic design and design structure matrix as functional decomposition approaches. Section 2.7 addresses data modelling techniques. Section 2.8 presents the gap analysis. Finally, section 2.9 summarises the chapter.

2.2 Design Requirement Change Management

Requirements management and Cost estimation are a necessary and important task to original equipment manufacturers (OEM) and their suppliers, especially in the design and manufacturing industry. Indeed, the complex and demanding nature of consumer requirements has led to a radical shift in the thought process of most organisations. The ability of companies to better manage changes during product development can decrease cost, shorten development time, and produce higher quality products (Rouibah and Caskey, 2003). Managing change is time-consuming and difficult within a single company. This becomes much more difficult if the product definition is performed across company borders.

Requirements are the needs of customers; these requirements (needs) are analysed and documented as engineering specification, which are in turn designed before being manufactured as a product. Requirement change in itself has no direct cost implication. The indirect cost implications of requirement changes are manifested during design phase. Products are continuously modified and changed. As a result most product development involves the steady evolution of an initial Design. Design changes are the consequence of the nature of the automotive industry.

Changes in requirements are usually accompanied by impacts; the cost and time impacts of these changes can be astronomical depending on the stage of the development process in which they occur. Requirements changes are also necessary, both to eliminate mistakes that have been made during initial design and manufacturing process, and to adapt the design to new requirements (Clarkson *et al.*, 2001). Often the final product cannot be visualised until design commences. Design changes are made for different reasons, such as more features and better performance. Cost of tooling can also be a reason to justify changing a part or component.

2.2.1 What are Requirements?

Requirements are "an elaboration, expansion and translation of the problem definition into engineering terms" (Shefelbine, 1998). The engineering definition must be translated to deliverable products, in product sectors such as the automotive, where large volumes of products are manufactured. Due to the changing needs of the automotive stakeholders, requirements evolve throughout the product lifecycle.

Requirements sometimes have constraints attached to them; these requirements and their constraints are constantly changing due to competition and the persistence of organisations to stay ahead (Roy *et al.*, 2004d). Constraints are defined as bounds on the design solutions that are acceptable to the customers. Constraints limit the set of acceptable design solutions and influence the definition and scope of requirements at lower levels of the design hierarchy (Tate, 1999). Constraints are the set of performance specifications and design restrictions that impact the product requirements and therefore limit the range of acceptable design solutions. Constraints ask "how well" specific tasks need to be performed. The performance specifications provided by the customer, management, government and industry standards, and safety regulations are specified as constraints at the system level.

Firesmith, (2002) espoused that requirements engineering is not trivial and can involve the production of a great many reusable work products that must be selected, integrated and tailored when producing a project-specific requirements process. Requirements engineering can be defined as the phase within an engineering process that identifies the scope of the work required to complete a product development.

The primary aim of requirements engineering is to identify the needs and create a knowledge base that will facilitate the comprehension of the efforts required for the creation of a product. The activities required to perform requirements engineering involves the following steps: monitor and manage changes, requirements specification during the project life cycle, traceability of documents and ensure the system developed is inline with the original specification (Firesmith, 2002). These steps facilitate the understanding of the requirements activities: elicitation, analysis and specification.

Requirements engineering is an agreement of both technical and non-technical requirements between customer and developers (Leinonen and Huovila, 2001). This agreement forms the basis for estimating, planning, performing, tracking project activities throughout the project life cycle, maintaining and enhancing developed product. Requirements Engineering deals with the:

- Resolution of all conflicting requirements at a very early stage of a project
- Feasibility of achieving the project goals and doing so within target cost
- Production of a glossary of all requirements
- Compromise between all stakeholders on issues identified, especially when there are resource implication
- Standardisation of all documentation and traceability
- What's and not the how's, including non-functional requirements (i.e. constraints)

The IEEE Standard Glossary of Software Engineering Terminology includes definitions of six different types of requirements:

- Functional
- Design
- Implementation
- Interface
- Performance
- Physical

These are applicable in the hardware environment, since all mechanical products exhibits six types of requirements. Within the automotive industry there exist number requirements as explained in Kerr *et al.,* (2004); in complex mechanical systems the product specification contains the following requirements:

- Layout
- Structural

- Regulatory
- Styling
- Marketability
- Cost
- Weight

Requirements in the software environment differ from requirements in the hardware environment. Since hardware products are tangible changes often incur more cost than software requirements. Cost function in hardware considers manufacturing cost, however manufacturing cost is not relevant in the software environment. Furthermore, the models for predicting changes in the software environment are not appropriate for mechanical design products. Since the links between parts are less explicit (i.e. involves more than one step) in hardware products compared to software products (Clarkson *et al.*, 2001).

Hoffman, (1994) claimed that requirements management is one of the key elements that must be addressed by concurrent engineering (CE) (Hoffman, 1994). However, management and representation of requirements is problematic in CE. Requirements are often ambiguous, incomplete and redundant in a CE environment. There is a lack of traceability of the requirements and insufficient decomposition of requirements (Kott and Peasant, 1995).

Jinxin *et al.,* (1996) argued that a major issue in concurrent engineering or collaborative design is the creation and maintenance of a suitable representation for design knowledge that will be shared by many design engineers. This knowledge includes many concepts such as component structure, features, parameters, constraints, requirements, and more (Jinxin *et al.*, 1996). Requirements generated by different members in a concurrent engineering team may be varied since different authors may have different viewpoint on what a system should be (Yen *et al.*, 1994).

2.2.2 Requirements Management

Requirements management has a critical effect on an organization's development costs and software quality (Sawyer *et al.*, 1999). The manufacture of high quality products is a necessity in today's marketplace. However, short life cycles, large product mixes, plus short design lead times often make it difficult to achieve this requirement (Das and Gami, 2004). Several authors have proposed requirements management approaches. A ontologically based requirements management process was proposed (Jinxin *et al.*, 1996). Other authors have developed fuzzy approaches to address complex and often vague problems in customer requirement management by applying fuzzy sets, fuzzy arithmetic, and/or fuzzy defuzzification techniques (Wang, 1999, Vanegas and Labib, 2001, Shen *et al.*, 2001, Zhou, 1998). Nonetheless, the interrelationships between requirements and product characteristics are often not properly integrated in the developed methods (Chen and Weng, 2003).

Tseng and Jiao (1998) recognize the rationale of functional requirements templates with respect to requirement management for product definition. Functional requirements templates are formulated to assist design engineers to define product specifications and present them in an organized and systematic manner. By analyzing existing products and historical data, the templates open opportunities for incorporating expert experience into new product design and enhancing the ability to explore and utilize underlying domain knowledge effectively (Tseng and Jiao, 1998).

Fiksel and Hayes-Roth, (1993) define requirement management as the process of creating, disseminating, maintaining, and verifying requirements. Furthermore, requirement management process consists of four main functions that are performed repeatedly in an iterative fashion (Fiksel and Hayes-Roth, 1993). These are requirement elicitation, requirement analysis, requirement tracking, and requirement verification this view was later corroborated in (Jiao and Tseng, 1999).

Svensson *et al.,* (2001), proposed a system that handle requirements management and requirements traceability in a PDM system. It was noted that the use a PDM system for requirements management demands extensive customisation of the system (Svensson *et al.*, 2001). A RM system can work together with a PDM system, since they support the same process, can also contain copies of the same information, this ensure traceability between requirements and parts.

Akin and Ozkava, (2002) proposed a dynamic framework that spans both design progression and alternative generation activities. It provides a more plausible model for design problems in terms of fault and error detection and change management where requirement engineering is crucial. However, its treatment of the requirements and solutions as a mono-directional operation introduces complications and difficulties in reverse engineering. Nevertheless, since it also handles each domain in its entirety, it facilitates a more comprehensive analysis of each domain (Akin and Özkaya, 2002).

The work procedures practiced for management of requirements in the automotive industry and those described in academic literature are becoming more harmonised (Almefelt *et al.*, 2003). Therefore, in the automotive industry requirements are established relatively early in the development process.

2.2.3 Requirements Management Tools

In this section, the author discusses how leading commercial requirements management software vendors provide storage for the reuse of knowledge and expert judgement within their applications. Three industry leaders are recognised as DOORS, Slate, and Calibre-RM. These tools provide a common base for the requirements capture, allocation, validation and verification in a design project, especially in the early phases of the project, or in a design organisation as a whole (Andersson *et al.*, 2003). However, these tools are not able to provide detailed impact analysis when a design requirement is changed. Each of these companies and their products are discussed respectively.

DOORS from Telegogic

'DOORS' is a tool primarily used in large organisations were there is a need to control complex sets of user and system requirements with full traceability. It provides good visualisation of such documents as hierarchies; its extension language enables a wide range of supporting tools to be built, and many are provided as menu commands and examples. Further options include DoorsNet, which allows controlled interaction over the Internet, and the Change Proposal System, which automates the requirement review cycle. There are live interfaces to many CASE tools, and the promise of tight integration with Telelogic's market-leading Tau toolkit for specification, design, and testing based on UML and the SDT approach to real-time systems development centred on telecommunications. Its use is therefore, moving towards integrated project support.

Slate from UGS

Slate consists of "Industrial Strength Groupware for managing requirements, designing systems, and accelerating product development". Tools cover design and testing as well as requirements. The examples on the website include radar and aircraft carrier, so there is a perceptible military-industrial orientation. The tool provides for conventional box-and-arrow diagrams, but also allows document and object hierarchies, and arbitrary traceability linking. An interesting feature is a budget, which provides a recursively added hierarchical spreadsheet for each attribute ('technical allocatable' in Slate jargon) which is to be budgeted. Slate is apparently genuinely object-oriented (OO) and as such should suit large industrial projects that want to use OO analysis and design. Some systems engineers see Slate as a tool that mainly supports the life cycle after the requirements phases. It provides limited support for requirements capture.

Caliber-RM from Borland

Caliber-RM is a well-known requirements management tool. It is intended for large and complex systems, and provides a database of requirements with traceability. The company views requirements as part of the software quality management process, which it considers also includes testing and defect tracking. Caliber is Internet-based, and it handles document references, user responsibility, traceability, status and priority among other features.

2.2.4 Requirement Changes

Andersson et al., (2003) presented a framework that makes it possible to not only to represent the outcomes of the design requirements process, i.e. contextual and product descriptions, but also enable the justification and reasoning behind the outcome of proposed changes. The objects in a complex product development process are connected through traceable links that makes it possible to support engineering change management activities (for example by identifying the subsystems that are affected by a requirement change or vice versa), or the follow-up of requirement fulfilment (Andersson *et al.*, 2003). Sometimes the supplier do not have the flexibility to cope with the requirement change (Huang *et al.*, 2003). Regardless of how requirements are defined they will change. In some cases requirement change is desirable (Kerr *et al.*, 2004b). This indicates that product development involves participation of stakeholders, since accommodating changing requirements is a measure of the product development team's stakeholder sensitivity and operational flexibility.

A change to one requirement may have an impact on other requirements. Managing requirement change includes activities such as establishing a baseline, keeping track of the history of each requirement, determining which dependencies are important to trace, establishing traceable relationships between related items, and maintaining version control (Kerr *et al.*, 2004a). It is also important to establish a change control or approval process, requiring all proposed changes to be reviewed by designated team members.

Changes are not necessarily a response to a defect; but rather a response to the need for improvement and enhancement of the capability of a product. When a change is proposed it might be more cost effective to change another part or component along the propagation path, than to change the component for which the initial change was proposed (Montesinos, 2004). Each change in requirement might have secondary impacts on related requirements and therefore propagate the change to other parts of the product. The propagation path is the nodes along a particular path in a set of defined relationships (Lock and Kotonya, 1999). The problem of requirement change management is further compounded by size of the information and complex relationships between requirement components (Lock and Kotonya, 1999). Requirements are also changed frequently during the design process due to the changes of technology and customer needs (Fox and Salustri, 1994).

2.2.5 Key Observations

- Requirements are defined as the needs of customers. It has been observed that requirements change as product development evolves. Therefore, it is important that requirements are managed. There are many requirements management tool, as explained in section 2.2.3. Although these tools are adequate for managing product requirements, changing requirements presents a challenge.
- Lam *et al.* (1999) states that there is a lack of theory and practice in the area of requirements change. They provided an overview and dissection of issues involved in the management of requirements change. Their approach is not directed towards any particular type of project but rather project managers are expected to select and use appropriate practices for selected issues. From this perspective the issues proposed are limited and requires further evaluation (Lam *et al.*, 1999).
- Literature reveals that requirement changes are common during any stage of a product life cycle (Black *et al.*, 1990, Chen and Lin, 2002, Kidd and Thompson, 2000, Oduguwa *et al.*, 2004, Terwiesch and Loch, 1999, Wright, 1997); here the focus is before production commences. Consequences of requirement changes are design change, unless properly anticipated and accounted for, can be costly. Therefore, it is highly desirable to obtain a mechanism that will be able to anticipate and evaluate product change consequences. The first task in anticipating and evaluating change consequences is to represent them.

The next section discusses requirements change impact analysis approaches. That is, what happens when a requirement is changed and how a change to one requirement affects other related requirements? Software and hardware environments are investigated for related research on impact analysis.

2.3 Requirements Change Impact Analysis

2.3.1 Software Development Environment

Impact analysis is the measurement of the impact of changing one component on other interrelated component in a system. There have been a number of studies in both the software industry (Han, 1997, Bohner and Arnold, 1990) and the mechanical design industry (Clarkson *et al.*, 2001, Cohen *et al.*, 2000). Requirement changes can have ripple effect that can sometimes propagate through system development. Ripple is said to occur when a change originating from one requirement affects one or more other related requirements.

The degree to which change propagates through a product depends on the complexity of the product itself. The complexity of product is defined in terms of the connections between its path, and engineering products are almost decomposable systems where connections between parts of a system can never be fully avoided (Clarkson *et al.*, 2001). "Ripple effect" is a common difficulty in making design changes. This can occur in several ways, but the basic idea is that a change in one procedure can require changes in another procedure, which in turn requires a change in other procedures.

For example, adding a parameter to a function will not necessarily require a change to all calling functions. If those functions do not have the information required to pass this extra parameter, they will need to add a parameter to their interfaces. This type of change can cause a 'ripple' of changes throughout the system. By changing a function's interface, the ripple is initially caused by a syntactic change to the function's interface. This only causes a required change to the immediate callers of the changed procedure. Determining if those procedures now need to change their interface is a semantic question, which means that dependency analysis alone will not be able to determine the extent of the ripple effect (Staples and Bieman, 1999).

Li and Jefferson, (1996) highlighted that a major problem for developers in an evolutionary environment is that seemingly small changes can ripple throughout the system to have major unintended impact elsewhere. A number of techniques exist to aid impact analysis: Pre-recorded traceability analysis, Dependency analysis, Plain experience analysis, and Extrapolation analysis as mention in Lock and Kotonya (1999). Visualisation (Staples and Bieman 1999) and Traceability of changes is another issue the software industry have implemented and incorporated into their tools (Cleland-Huang, Chang et al. 2002).

Over the years, impact analysis has been defined from different perspectives. Impact analysis is a technique that identifies the parts of the software system that will be affected by a change, and by estimating the cost and effort required to make those change (Cleland-Huang *et al.*, 2002). It is the activity of identifying what to modify to accomplish a change, or of identifying the potential consequences of a change (Abbattista et al., 1994). The consequences of change are cost, time and resources, since a manifestation of any leads to increase in cost.

Impact analysis (also referred to as *change impact analysis*) is the process of determining the potential effects of a software code change (Staples and Bieman, 1999). Impact analysis starts when a programmer is given a change request and finish with identifying which modules change(Abbattista *et al*., 1994). Impact analysis is the process of identifying the potential consequences of a change, or estimating what needs to be modified to accomplish a change (Arnold and Bohner, 1993). The evaluation of the many risks associated with the change, including estimates of the effects on resources, effort, and schedules (Pfleeger, 1991).

In summary, change prediction would be useful both at the tendering stage of a new project, to assist project planning, and during the subsequent redesign, to assist identification of previous instances of change propagation (Clarkson *et al*. 2001).

2.3.2 Mechanical and Hardware Environment

Aerospace Environment

The early findings of this research were applied to the aerospace industry in a masters thesis. In 2004 the author shared some of his observations with a Masters student carrying out a 4 months feasibility study of cost impact analysis in the aerospace industry. The Masters project was titled “Cost Impact Analysis for Requirement Changes within the Aerospace Industry” (Montesinos, 2004). The study focused on the spa and wings of an aeroplane as single systems. The impact of changing one aeroplane system on other related system was not investigated this was mainly due to time constraint.

During bidding, the aerospace OEM provides more details to their suppliers than automotive industry where the suppliers are expected to spend more time on developing innovative ideas. This may be due to the automotive OEM's lack of knowledge on what the product should look like, since most automotive products starts as a conceptual idea. Another reason for extreme data protection is due to the many suppliers available for automotive systems. There are not many suppliers in the aerospace industry.

The aerospace cost impact analysis based cost on "Strength Relationship Code" which depends on previous estimates. Strength Relationship Code is particularly useful for design parameter analysis. Due to time constraint the Aerospace methodology is only able to address internal impact. Cost impact analysis is assessed using cost drivers as in automotive industry, but cost drivers are broken down into recurring and non-recurring cost (Roy *et al.*, 2005). The automotive cost impact analysis methodology adds non-recurring cost as a percentage of total delta cost.

Aerospace products have longer life cycle than automotive products; a fundamental difference is the product change cycle. For a car this may be between 2 to 4 years. For an aircraft, it could be 25 years or more. There are more regulations governing the way aerospace industry operates than those of the automotive industry. The regulations place enormous restraints on the ability to change suppliers.

Another difference between automotive and aerospace is, of course, the much smaller volumes. While automotive manufacturers may look to the production line for waste reduction opportunities, the aerospace industry is likely to focus on its information processes. Unlike the automotive industry, the aerospace industry has less than a handful of major OEMs and few launches of new aircraft.

Construction Environment

Davis (1994) presented a method that implies the use of certain assumptions. First, his cost estimates are based on the assumption that the unit is constructed. Second, the estimates are based on past construction practices. It was noted that the details of the designs of representative houses, with the exception of the aspects of the construction modified by the code change, are likely based on characteristics of houses as they are currently built. Cost impact estimates for a proposed change imply that these construction practices will continue into the future. Third, there are no market adjustments to changes in cost. In producing aggregate cost impact estimates for a representative type, the per-unit cost impact estimates are multiplied by the number of units anticipated to be constructed. The number of units anticipated is apt to be based on published projections derived without consideration of market adjustment in reaction to the cost impact of the code change. This static approach was taken in order to produce a methodology that would be usable by people with no expertise in such specialised fields as econometrics.

Mogge (2004) presents as a bridge, the framework connecting two models, the built environment and the sustainable infrastructure models. Operating like a decision support system, the framework in effect, bridged the models with a structure of sustainable strategies that are reflective of the many planning, design and construction decisions taken in the course of delivering a project. The bridge should be viewed and used as a two-way bridge, with both directions leading to accelerated use of sustainable planning, design, and construction. One direction through forward chaining is for the use of planners, designers and constructors, and the opposite direction, through back chaining, is for the use of owners, and policy makers. This allowed his framework to be used both as an actual project tool, and as a support tool for policy decisions regarding sustainable outcomes. The model depicted multiple stakeholders, many more than the principal process actors. It was in this larger context where the framework has its greatest value. It allowed a method to communicate complex decisions to many stakeholders by linking the decisions of the process in a holistic but largely sequential manner.

Mogge (2004) further explained that outside of a scenario based application, a project team for a facility project with all of the actors present would begin the use of the framework with the desired strategies in the framework and their understanding of the cost impact for each strategy mapped to it. With the entire process mapped, inspection, pattern detection, qualitative coding, and perhaps causality techniques of analysis would be followed and used to form the integrated project decisions with respect to cost impacts. This is essentially a design to cost approach but executed across the entire delivery process and within the framework.

2.3.3 Other Environments

Health Environment

Kominski *et al.*, (2004) developed the California Cost and Coverage Model, which is the first comprehensive effort to develop an "open source" model by actuaries and health services researchers to estimate the effects of health insurance benefit mandates for different types of insurers and for different employer firm sizes. They argued that typically models of changes in health insurance premiums are not widely available in the public domain and until recently, were largely developed and used by actuarial firms for private clients. Evaluating the impact of a mandate for one insurer or employer, using claims data, is considerably easier than estimating differential effects on an entire market. As more states become interested in evaluating the financial impacts of mandates, actuarial models can be developed in a timely and transparent manner so that researchers and stakeholders can assess the quality of the data and assumptions used to estimate the impacts of benefit mandates.

Borzekowski (2002) suggests that several features of hospitals and hospital information systems limit the applicability of traditional hardware based measures of IT and encourage an application-based framework. This research takes advantage of the system-by-system structure of health information sector, as well as a rich dataset of nearly 3000 hospitals to create new application-based measures and to assess whether IT is associated with lower hospital costs during the early 1990's.

Marine Environment

Glueckstem *et al.,* (2001) argues that improvements in seawater desalination technology and the dramatic reduction in costs offer the most practical solution to cope with the current water crisis in Israel and in the region. However, from impact on the environment and macroeconomics points of view, the more complex solution of treating marginal sources must also be considered. He explained that recent improvement in desalination membranes and tailored optimised information management systems for specific applications to a variety of marginal sources would most probably increase the competitive utilization of marginal sources as a viable alternative to seawater desalination. The author suggested that the incorporation of large amounts of marginal sources as a part of the total required desalinated water capacity would remarkably reduce the water supply cost and the negative impact on the environment.

2.3.4 Key Observations

- The high uncertainty dimension in cost estimation and its influence on the nature of the complex product industry means that cost impact analysis problems are complex. Hence, this poses challenges for methodology creation.
- A common theme across impact analysis practice is the need to decompose the domain (system) into requirements and solutions. Hence, allowing analyst to establish relationships between requirement and solution.
- The main benefit of impact analysis is that it will help in determining the expected cost of the change and will aid the decision as to whether a restructuring is in order (McCrickard and Abowd 1996).
- Although these approaches exist mainly for software design changes, they are not appropriate for mechanical design where the parametric links between parts might be less explicit for the predictions of change involving more than one-step (Clarkson, Simons *et al.,* 2001).
- It was observed that the aerospace industry is more willing to share data, though competition is fierce. However, the automotive industry is not so willing to share data; benchmarking is usually very expensive and closely guarded.

The next section examines cost impact analysis practices and there relevance to the mechanical design industry.

2.4 Cost Impact Analysis

Cost impact analysis is the assessment of cost implications when a state is altered. Cost impact analysis has two main areas: Impact analysis and Cost assessment. Impact analysis is specific to a domain, for example, the impact analysis of changes on a process. Cost assessment is the cost estimation process of an altered state. There has been several requirements change impact analysis research within the health and transportation industries (Edwards, 2000, CalISO, 2000, Scotland, 2005). However, there is little research in the area of cost impact analysis within the automotive environment.

The association of cost engineers defines cost impact as “an effect or influence of some occurrence, commonly a change, on an existing cost budget or forecast, while, cost analysis is defined as a systematic breakdown of cost data into elements for detailed examination” (ACostE, 2000). In (Lee and Jeziorek, 2004) cost impact analysis is defined as how much will the cost increase in the event of a requirement change? These two definitions together represent what cost impact analysis (CIA) is in practice, a term that has really been defined in the academic literature. The aim of cost impact analysis is to assess incurred cost when a design requirement change is proposed to mechanical design components and the impact of that change on other related components.

In (CIMdata, 2001) it was argued that project managers can perform cost impact analysis and then trigger the corresponding follow-up actions, such as the creation of an engineering change request (ECR). This functionality can be used as a generic change request before a formal ECR is created.

2.4.1 Challenges in Cost Impact Analysis and Requirement Change Management

Cost will be a constant source of concern, particularly before considering different technical options, in conducting cost/technical trade-offs, in establishing budgets, in the submission and evaluation of price proposals, in preparing for contract negotiations, and in assessing the cost impact of introducing changes to existing designs (Greves and Joumier, 2003). The question is how to tackle these aspects to be best able to predict or assess cost, how to minimise the risk and impact of overspends against budgets, and how to ensure that there is an appropriate balance between technical aspects and the related costs.

The above discussion leads to a conclusion that a good cost estimation method should provide critical insight into 'how much' a system will cost and 'why'. Once a cost estimation method can answer the question of 'why', then it will also be able to address the problem of determining the cost impact of a design change, i.e. how much will the cost increase in the event of a requirement change? These questions can only be answered when the system design knowledge/information is closely linked with relevant cost information (Lee and Jeziorek, 2004).

As a first step toward the complete life cycle cost assessment tool, the author developed a method to determine the cost impact of a change to the development of a system (Lee and Jeziorek, 2004). The main goal of the method is to identify the components that would be affected by a change made in the functional domain and then determine the change in cost of the development labour. Here the development cost is the sum of the labour and material costs and investment into infrastructure. The cost of infrastructure is not considered in this cost estimation effort. A simple proportionality rule of labour and material was employed to estimate the total development cost (Lee and Jeziorek, 2004).

In another related cost impact research, a framework to address the problems in cost engineering was developed. The framework provided a structure to integrate a system design knowledge/information with the cost information. In particular, as a first step toward the grand goal, a preliminary cost model for a development phase of a system life cycle is presented. The model renders the information flow between engineering requirements, design solutions, their embodiment and cost data tied to tasks/processes required for the physical implementation. This model is developed based on the Axiomatic Design process. It offers an effective way to examine the completeness of the scope of estimation to ensure the first order of the credibility of the estimates. It also provides traceability between individual domains within the development phase, which is particularly useful in assessing the cost impact when a change is introduced to a system at certain point (Lee and Jeziorek, 2004).

Requirements change management functionality would determine the 'likely knock-on effects' and consequences of a proposed requirement change, with cost impact being a special sub-function. Using the requirements repositories as the single shared source of information, requirements changes could be automatically updated through the supply chain to suppliers either directly involved or impacted by an OEM change. This automatic provisioning of only the actual updated change, as opposed to the whole document, would reduce the designer workload and manual collection effort through the use of a single, fast and easy to use front-end reporting tool (Kerr *et al.*, 2004b).

Lam *et al.*, (1999) espouse that impact analysis is the process of assessing the impact that a requirements change is likely to have on existing functionality and quality (e.g. performance, safety, reliability, usability) of a system. In addition, impact can be rated on a scale: high, medium and low (though organisations may wish to devise their own impact schemes) (Lam *et al.*, 1999). In practice, there is seriously lacking a rigorous methodology to identify and assess the cost impact of design requirements changes.

Features of Impact Analysis

Change management is a mechanism for providing information required for assessing proposed changes, of which impact analysis is dependant. Impacts are identified within a system when changes occur, by analysing the system. The size of the component to be changed is directly proportional to the time it takes to analyse the component for impact. The degree to which change propagates through a product depends on the complexity of the product itself (Clarkson *et al.*, 2001). Complexity is related to size; the more the problem space the more time and effort required to analyse it. Cost of Proposed Change, impact analysis needs to be managed and assessed to ensure that changes are feasible, make economic sense, and contribute to the business needs of the customer organisation.

Traceability links (relationship) are an essential aspect of impact analysis and established relationships between requirements and design parameters. That is, the component that has been changed and related components that can be affected by the change. Propagation Path (Actual Link) can be used for the visualisation of the effect of proposed changes (Bohner and Arnold, 1990). Propagation of effect, change in part A might have an effect on B, B in turn might have side effect on C. The chain of effect is referred to as propagation effect or propagation path.

Traceability is the degree to which a relationship can be established between two or more products of the development process, especially products having a predecessor-successor or master-subordinate relationship to one another (Bennett, 1996). Traceability links define the relationships that exist between requirements and other engineering parameters (Cleland-Huang *et al.*, 2002). Level of Abstractions/Entities, (Moriconi and Winkler, 1990, Ajila, 1995, Goradia, 1993, Li and Jefferson, 1996, McCrickard and Abowd, 1996, Han, 1997) were concerned with the hierarchical structure of the product, the product with first need to be decomposed, using decomposition techniques such as axiomatic design (Lee *et al.*, 2001), or design structure matrix (Browning, 2001, Yassine, 2002). Both techniques are graphical and visual; traceability links and the propagation path can be determined from the resulting matrix.

2.4.2 Key Observations

- Most of the research in cost impact and impact analysis estimates the cost of changes subjectively. These estimates require a cost estimation approach in order to be valid, reliable and justified. A common theme across the research is the introduction of change.
- Another observation is that the changes if not properly managed can have severe negative consequences. Impact assessment can be measured as cost impact. Impact also needs to be estimated.
- Cost impact analysis is an important aspect of the design requirements change management within the complex product development environment. However, there is limited research in the automotive sector concerning cost impact analysis (Roy *et al.,* 2004).
- In a related cost impact analysis research it was noted that, at the conceptual

design stage, an accurate and detailed cost analysis is not possible because detailed manufacturing plans have not been prepared (Chan and Lewis, 2000).

- Literature reveals that requirements changes and design changes are common during any stage of a product life cycle. Consequences of these changes, unless properly anticipated, and accounted for, can be costly. Therefore, it is highly desirable to obtain a mechanism that will be able to anticipate and evaluate product change consequences. The first task in anticipating and evaluating change consequences is to represent product requirements.

The next two sections discuss several common techniques and tools.

2.5 Cost Estimation

Cost estimation is “the art of approximating the probable worth or cost of an activity based on information available at the time" (Stewart, 1991). Cost estimation of a product or service is essential for an organisation. Since cost is the main factor that gives an organisation the competitive edge over other competitors. Cost estimates need to be consistent to be able to rank alternatives. Absolute cost will be dependant not only upon region of manufacture and assembly, but also upon market conditions and price levels when tenders are awarded. The detail design/manufacturing companies calculate their costing on detailed material and equipment listings, and make full use of labour (Crozier *et al.*, 1994).

Cost is an important performance measure, especially in the private sector. Since profit is defined as the difference between the selling price of a product and the cost of manufacturing the product. To increase profit an organisation can increase the selling price, decrease the cost, or do both. The exact relationship between the selling price and sales is hard to predict. Since an increase in the selling price in an effort to increase profit per product unit, may result in decreased sales. Therefore, a better approach to increase profit is to reduce products manufacturing cost. Reduction in manufacturing cost can be translated to higher profits per unit, keeping the selling price constant.

Cost estimators are usually asked to calculate costs on a completed design proposal and their input is seldom possible until late in the design process, when the major design decisions have been taken and accepted as the basic form of the project. In addition, the difference between an estimated cost and an actual cost is that only the most important factors are considered in the estimation process. Some minor elements or factors, which cannot be predicted, are not given attention during the estimation (Winchell, 1989).

Underestimating leads to drastic consequences in organisations were the task cannot be completed as estimated. Extra resources are consumed and schedule limits are broken. Therefore, it is paramount that an organisation is able to provide credible and reliable cost estimates (Filipan, 2005b). Underestimation does not only have adverse effect on profitability and quality, but also on the creditability of an organisation. Overestimating on the other hand, can lead to the lost of important business. However, if a project is awarded on higher quotations, the design and manufacturing activities expand to consume more resources.

Cost Estimation during the early design stage; is one area that has been given little attention by researchers. However, if the product manufacturing cost can be estimated during the design stage, designers can modify a design and achieve proper performance as well as a reasonable cost at an early stage of the product development process. Manufacturing cost is determined by product complexity, product precision tooling process. That is, if these data can be obtained and considered during the design stage. Cost estimation during the early product development stage will become a feasible task (Ou-Yang and Lin, 1997).

The methods of estimating used in practice depend upon the experience of the organisation and availability of historic data. Lack of sufficient detail in the specification tender documents, followed strongly by having inadequate time to assess and cost design requirement and impact of required changes, create a challenge to the environment for cost estimator and design engineers. Irrespective of whether cost estimation is viewed as art, science or an amalgam of both, there is a need for a more integrated, responsive and hopefully more accurate cost estimating system, aligned more closely to the concept design process (Crozier *et al.*, 1994).

2.5.1 Cost Estimation Techniques

There are several cost estimating techniques, in practice the techniques of used depend on the experience of an organisation and the availability of historic data. Based on the project's scope, the purpose of the estimate and the availability of estimating resources, the estimator can choose one or a combination of techniques when estimating an activity or a project (Sarasua *et al.*, 2004). Estimating techniques, estimating indirect and direct costs and other estimating considerations are discussed. Some techniques are better than others depending on the context. (Duverlie and Castelain, 1999) presents an approach for selecting a technique. A few or the techniques are mentioned.

Parametric

Parametric estimating requires historical databases on similar systems or subsystems. Data is derived from the historical information or is developed from building a model scenario. Statistical analysis is performed on the data to find correlations between cost drivers and other system parameters, such as design or performance parameters. The analysis produces cost equations or cost-estimating relationships that can be used individually or grouped into a more complex model (Collopy and Curran, 2005). This technique is useful when the information available is not very detailed.

The basic idea is to group similar products into classes and then basically use the mass as an indicator for cost within a class. Models are created from historical data (Roy *et al.*, 2004b), which represents the cost without necessarily going deep into the functionality of the system. Typical driving input parameters are the mass, design and manufacturing complexity, and elements of new mechanical/electrical design. Parametric is a quick way to calculate a cost, but needs an experienced estimator to ensure consistent results. Parametric methods use the knowledge of a certain number of physical characteristics or parameters such as the mass, the volume, and the number of inputs–outputs.

Cost estimating relationships (CER) are formulae that calculate the cost of an item based on the cost driving technical parameters (Roy, 2005). They are well suited for smaller units/products where more comparable units are available and accurate specifications are easy to obtain. The formulae are derived from statistical correlation/regression and must be checked carefully for their validity, the range of parameters, and the applicable field (Colmer, 2005). Colmer (2005) further identified CERs through regression analysis by analysing automotive cost data to reveal cost drivers by first developing.

The "quality" of a CER is mainly determined by correct extraction of the cost driving technical parameters. The results are accurate estimated costs that are supportable. On the other hand, this method requires extensive preparation in advance in order to be able to apply the CER. Systems or Sub-systems must be broken down to units where CER are applicable. CERs are also used for cost-to-cost relationships, i.e. linking support cost (Management, Engineering, Product Assurance, etc.) to production cost. Very few parameters are needed and many examples are available for in-depth analysis.

Analogy

The analogy method also known as case based reasoning, which attempts to evaluate the cost of a set or a system from similar sets or system (Duverlie and Castelain, 1999). As the name suggests, analogy makes use of the similarity of products. It is implicitly assumed that similar products have similar costs, though this does not always hold, especially in cases where different geographical regions are involved, where labour rates can vary significantly, and the amount of development required might vary from project to project. Nevertheless, the basic principle that similar products require a similar amount of effort is valid. Analogy estimates require one or more similar item in terms of their purpose and their technical performance. Once a database is available, this method can generate quick and reliable estimates by comparison of items. The method requires the means to identify the similarity of items, which is the crucial point in using this estimating technique, but also to identify differences for which adjustments can be made (Ling *et al.*, 2006, Filipan, 2005a, Filipan, 2005b).

Analogies depend upon the known cost of an item used in prior systems as the basis for the cost of a similar item in a new system. Adjustments are made to known costs to account for differences in relative complexities of performance, design, and operational characteristics. Analogy provides the ability to quickly propose a solution (Ling *et al.*, 2006). Moreover, it functions in a transparent manner. At any time, the user knows the origin of the solution and can correct the result. The analogy method is often used to solve problems where no obvious formalisation of trade knowledge exists, which is often the case for complex sets.

Several applications of analogy method have been reported in areas as varied as medicine, design assistance with the diagnosis, planning, etc. In fact, it concerns areas where the reusing of past solutions represents an important part of the task (Duverlie and Castelain, 1999).

Detailed (Bottoms-Up)

Generally, a work statement and set of drawings or specifications are used to "take off" material quantities required to perform each discrete task performed in accomplishing a given operation or producing an equipment component. From these quantities, direct labour, equipment, and overhead costs are derived and added. This technique is used as the level of detail increases as the project develops.

The costs are calculated from assessed hours needed for each work-package. The approach requires a detailed knowledge about the project objectives, the organization, the work-packages, and their description (Roy *et al.*, 2003). The hours for each work-package are assessed for the different needed labour categories. The total costs are the direct labour cost plus the indirect cost for non-labour (material, equipment, fees, etc.). The costs are summed up to the highest level and represent then the cost (i.e. price) of the project. This gives an accurate cost and also serves as an excellent planning tool during the execution of the project. One of the weaknesses of this method is that it is a time-consuming way to get a cost figure for a project. Since it requires the designers, engineers and estimators to go through work statements and drawings, which might be many.

Expert judgement

Expert judgement is often regarded as being subjective and open to bias, since the suggested opinions are that of an individual or group of individuals (Rush and Roy, 2001b). The bias can be economical or political, depending on the nature of the product under consideration. This gives the critics of expert judgement a reason to justify their negative view of what expert judgement is and can do. Nevertheless, expert judgement is widely use and has been proven to outperform conventional techniques of solving cost estimation problems (Rush and Roy, 2001b).

Traditional estimating is widely used although some experts argue that calling it a technique is an exaggeration, but merely a way of estimating cost when other techniques are not available (Fatelnig, 1996). The traditional method is sometimes referred to as expert judgement technique or intuitive method (Duverlie and Castelain, 1999) or rule of thumbs (Fatelnig, 1996). Often experts working for a long time in a business develop a fairly good knowledge of the cost of a product in their field. The resulting estimate is subjective and dependent on the estimator's knowledge. This method is useful when other techniques or data are not available. This method is also useful in the early phase of the project where costs at a Rough Order of Magnitude (ROM) are necessary.

Feature based

The growth of CADCAM technology over the past decade, especially that of 3D modelling tools, have largely influenced the development of feature based costing (FBC) (Roy *et al.*, 2004b). Several researchers have investigated the integration of design, process planning and manufacturing for cost engineering purposes using a feature based modelling approach (Wierda, 1991, Bronsvoort and Jansen, 1994, Catania, 1991, Ou-Yang and Lin, 1997). Although FBC has not attain full established or development in the cost engineering community. Nonetheless, there are several good reasons for examining the use of features as a basis for cost estimation during product design phase. It has been observed that each product feature has cost implications during production, since the more features a product has the more manufacturing and planning it will require (Brimson, 1998, Roy *et al.*, 2004b). Therefore, choices regarding the inclusion or omission of a feature impact the downstream costs of a part, and eventually the lifecycle costs of the product (Rush and Roy, 2001a, Roy *et al.*, 2001).

Table 2-1: Examples of features (Roy, 2003)

Feature Type	Examples
Geometric	Length, Width, Depth, Perimeter, Volume, Area
Attribute	Tolerance, Finish, Density, Mass, Material, Composition
Physical	Hole, Pocket, Skin, Core, PC Board, Cable, Spar, Wing
Process	Drill, Lay, Weld, Machine, Form, Chemi-mill, SPF.
Assembly	Interconnect, Insert, Align, Engage, Attach.
Activity	Design Engineering, Structural Analysis, Quality Assurance.

Despite the recognition of feature based cost estimation, there are limitations for using it as a cost estimation technique. There is no widely accepted consensus on what a feature is across the complex product development community. This problem is magnified when viewed across companies and industries. With respect to this problem, companies are faced with producing their own feature definitions. Table 2-1 illustrates with the aid of an example, how one cost engineering group categorised features for the purpose of costing (Taylor, 1997). This illustration depicts one level of feature definition; however, there are several levels of features definitions. For example, a physical feature of an aircraft could be a wing, yet this wing contains many parts, each of which consists of many lower level features. Therefore companies are left to decide how to cope with the changing product definition and applying an appropriate feature based CER. Thus, the feature based costing approach is not yet fully established and the implications are not yet completely understood.

Activity based

Activity-based costing (ABC) creates cost elements by observing overheads in relation specific manufacturing activities. These costs are obtained from derived cost drivers associated with the activities required to manufacture products. Based on historical or estimated data the cost per unit of the activity's output is calculated. The estimated cost for a new product can be obtained according to the products consumption of these activities (Zhang *et al.*, 1996). ABC depends on accurate data, hence not useful during conceptual design. It also requires complex systems to maintain activity information. Feature costing is an alternative approach as it uses less data to create a product cost (Brimson, 1998). ABC is ideal for optimising production and identifying high costs of manufacturing processes. It more realistically allocates costs to small batches (Souchoroukov *et al.*, 2002).

Rule based

Rule based cost estimations are hybrid cost estimation methodology combining bottom-up cost estimation and expert opinion technique. The difference between an estimated cost and an actual cost is that only the most important factors are considered in an estimation process. Some minor elements or factors, which cannot be predicted, are not given attention during the estimation.

2.5.2 Cost Estimating Tools

In this Section, the author discusses how leading commercial cost estimating software vendors provide storage for the reuse of knowledge and expert judgement within their applications. Three industry leaders are recognised as PRICE Systems (Price, 2005), Galorath (Galorath, 2005) and Cognition (Cognition, 2005). Each of these companies and their products are discussed respectively. This review is based on a previous research (Rush, 2002).

PRICE Systems develop a suite of parametric cost estimating products such as PRICE H, PRICE S, and more recently Knowledge Manager. Within the PRICE H, and PRICE S cost models, users input assumptions and judgments using a 'free' text notepad. There is no formalised process by which to use the notepad and no guidance on how best to extract information from the user. The PRICE Knowledge Manager is a new concept. It provides a data centric view of reusing knowledge opposed to a human centred view. For example, users develop customised cost estimation relationships (CER) with the Knowledge Manager, which can subsequently be used as part of their estimate. Whilst this aids the reuse of underlying data, it does not facilitate the reuse of decisions, assumptions, and rationale related to the development and use of the CER.

Galorath Incorporated develop parametric based products known as SEER-H, SEER-S and SEER-DFM. These have a similar notepad function to input judgements, and assumptions. Galorath's product allows notes to be inputted for specific elements of each cost estimate. However, the same issues arise with respect to no formal process or guidance related to capturing expert knowledge and judgements.

Cognition develops nonparametric software systems known as Enterprise Cost Management (ECM), and Cost Advantage. ECM creates a central repository for linking the sources of data and systems used to develop cost estimates. In this way, it provides a reuse facility. It combines a human and data centric view with respect to the capture of reuse of expert knowledge. This is because estimates can be given a context. A context comprises details such as economic conditions and assumptions about material and labour prices. In this way, the user inputs judgments to assess how they affect the estimate. A limitation of the context feature is that it applies to the entire estimate. Since an estimate is made up of many smaller estimates, the context may not be applicable for every part of the estimate. The rationale and judgments used to make the assumptions within a context are not captured in a formalised way. Nonetheless, the concept does provide a more human centred approach to capturing knowledge.

In summary, whilst there is a facility within current commercial cost models to store assumptions and knowledge, the means to do so are limited. A common observation across all three cost estimation tools is that cost estimation of changes are not catered for. When a change is made to the data in the tools, a new cost estimate is generated. There is no formalised process to facilitate the input and capture of expert knowledge. This makes understanding and reusing estimates a difficult process. As mentioned previously, the judgements used during the input of cost model values have a significant effect on the estimate results. Unless the judgements are captured, others cannot understand how the estimate was derived. New concepts such as Knowledge Manager and ECM are predominantly based on a data centric view of capturing and reusing knowledge. Whilst these systems are moving towards the reuse of cost engineering knowledge, more effort is required with respect to capturing the human aspects of cost engineering knowledge. By doing so, expertise and judgement will be better integrated with the final cost estimates making estimates understandable and reusable.

2.5.3 Cost Drivers

Cranfield University has been involved in cost estimation related research with emphasis on cost driver (Dauda et al., 2005, McGrath, 2005, Colmer, 2005, Souchoroukov et al., 2002, Curran et al., 2002, Roy et al., 2004a, Roy et al., 2005).

Souchoroukov (2004) postulated an approach that can be used to help identify cost drivers for cost estimating relationships (CERs) and provide a link for commercial and engineering people to communicate cost-impact decisions better is proposed. This approach is based on the use of Functional Decomposition Techniques for Cost Estimating at the Conceptual Design Stage (Souchoroukov, 2004).

Ten Brinke *et al.*, (1999) emphasised the use of cost drivers in the creation of their cost model. The work details the creation of a cost model based on information about the product to be estimated (Ten Brinke *et al.*, 1999). Wang and Stockton, (2001) identified three major tasks involved in the creation of a cost model: data identification, data collection, and data analysis. These three tasks form the basic information required in the creation of the cost model (Wang and Stockton, 2001).

McGrath (2005) observed that there is a lack of research in the field of cost estimating for painted plastic commodities. His research identified cost drivers for plastic commodities and determined what the effect of all these cost drivers have on the cost of a painted exterior component in the automotive industry (McGrath, 2005).

2.5.4 Key Observation

- The data available and the level of details required in an estimate will determine the costing method used. Of course, no model can be described as universal. In practice, the use of one method alone is not sufficient. For example, some costs, such as set-up costs, are well fitted to the analogical method while a parametric method is preferred to estimate, for example, the raw material cost of a reduction crankcase (Duverlie and Castelain, 1999).

- All of these methods rely more or less on data from past projects/programs, which implies that it is necessary to have historical data available and ready for usage. Those data can come from past proposals, which represent the cost commitment from industries for a certain technical proposal. However, in the automotive industry, CIA requires knowledge of DRC for design and development. The primary objective is to minimise the impact on cost when a DRC is necessary.
- Knowledge of the costs can be obtained through the cost drivers, i.e. the cost driving product characteristics. These cost drivers can be related to the fundamental structure of a system (Ten Brinke *et al.*, 1999). For example, the fundamental structures of a car seating system are foam, fabric, steel and plastic. These can be related to the cost drivers of the seating system (tooling, raw materials, labour etc). The estimated cost might be near to the actual cost but might have certain deviations from it. However, the estimated result can provide guidance for the estimators to justify cost estimates.

At the end of section 2.4 axiomatic design and design structure matrix were identified as potential decomposition approaches to determine relationship and establish traceability links between requirements and design parameters. The next section examines the concepts of axiomatic design and design structure matrix.

2.6 Functional Decomposition Approaches

Methodologies and techniques, offered in the literature, such as axiomatic design (AD), design structure matrix (DSM) and quality deployment function (QFD) have been endeavours towards the establishment of rigorous methodologies for developing quality products. However, such methodologies are addressing mainly the development of design parameters or engineering characteristics, and subsequent new product concepts. There is a lack of effective approaches and tools for establishing explicit relationships between customer or stakeholders needs and product requirements. Firstly, this requires specification of a means of representing stakeholders needs and product requirements, and secondly, an establishment of mechanisms for formalising relationships between stakeholders needs and product requirements (Agouridas *et al.*, 2001).

2.6.1 Axiomatic design

Axiomatic design (AD) provides a means of representing and decomposing higher-level functions requirements (FR) and physical embodiments (called design parameters, DPs) until the creation of leaf-level FRs and DPs that can be implemented to construct the system according to the resulting design decision architecture (Pallaver, 2003). AD enforces complete decoupling of elements of a component to a tree structure; the problem with this is that coupling in some products are not always possible. To use AD successfully, it is recommended that the initial design of a product will be done in AD. Many researchers have implemented AD for automotive systems (Bae *et al.*, 2002, Cochran *et al.*, 2000, Gould, 2000, Pang, 1999). One of the most important advantages of AD is its hierarchical structure, which alleviates the complexity associated with design process (Houshmand and Jamshidnezhad, 2002). AD enforces complete decoupling of elements of a component to a tree structure (Suh, 2001). Based on Nam Suh's experience (Suh, 2001) and observations about existing designs and his assessment of successful and unsuccessful designs, he proposes two axioms and some corollaries to govern the axioms:

- **Axiom 1**: Maintain the independence of the functional requirements
- **Axiom 2**: Minimise the information content of the design

A specific problem is that the requirements are often coupled which makes its difficult to analyse the effects of a requirements change or a product design change. This is particularly problematic in the early phases when the information available at early phases is vague. Existing analysis tools, e.g., stress analysis, digital mock-ups, kinematics' etc, requires data with a high degree of detail and are therefore typically limited to use in the later phases of product development process (Sutinen *et al.*, 2002). Depending on the type of resulting design matrix [A], three types of designs exist: uncoupled, decoupled and coupled. Coupled: A coupled design exists when the FRs and DPs are inextricably linked, preventing the independence of the FRs and producing a densely populated design matrix. Decouple: A decoupled design occurs when the FRs are dependent upon the DPs in such a way that the independence of the FRs (axiom 1) can only be guaranteed by determining the DPs in a proper sequence. This produces a triangular matrix. Uncouple: An uncoupled design exists when each DP fulfils a single FR, creating a one-to-one relationship between requirements and design. This produces a matrix in which all couplings appear on the diagonal.

Similar to FRs and DPs, constraints are refined and clarified as the decomposition progresses. Many high-level constraints also influence the specification of lower-level FRs. In general, the more constraints that exist at the system level and the more restrictive the constraints, the harder it will be to generate an acceptable design solution. Accordingly, the harder it will be to maintain functional independence while minimizing the information content.

2.6.2 Design Structure Matrix

The representation of consequences is the subject of the work by Donald Steward work (Steward, 1981) design structure matrix (DSM); here elements of a component are arranged similar to the rows and columns of a matrix. DSM provides the means of determining the impact of changes and propagation path. Many researchers have used DSM to analyse the impact of changes in element level interactions; DSM also uses partitioning, tearing, and clustering to aid the decoupling of components/systems (Yassine *et al.*, 2001).

In (Cohen *et al.*, 2000) a methodology called Change Favourable representation (C-Far) is proposed, for representing design changes based on vectors; however this approach is only suitable for components with a small number of parts. DSM is used to determine the propagation path of change impact.

A change propagation predicting approach is presented (Clarkson *et al.*, 2001) where system components are represented as elements of a matrix, and uses direct likelihood and direct impact to determine the risk of a change propagating to other elements. Likelihood is defined as the average probability that a change in the design of one sub-system will lead to a design change in another by propagation across their common interface. Similarly impact is defined as the average proportion of the design work that will need to be redone if the change propagates. Both these quantities are assigned values between 0 and 1, and refer to the total change experienced during the redesign process.

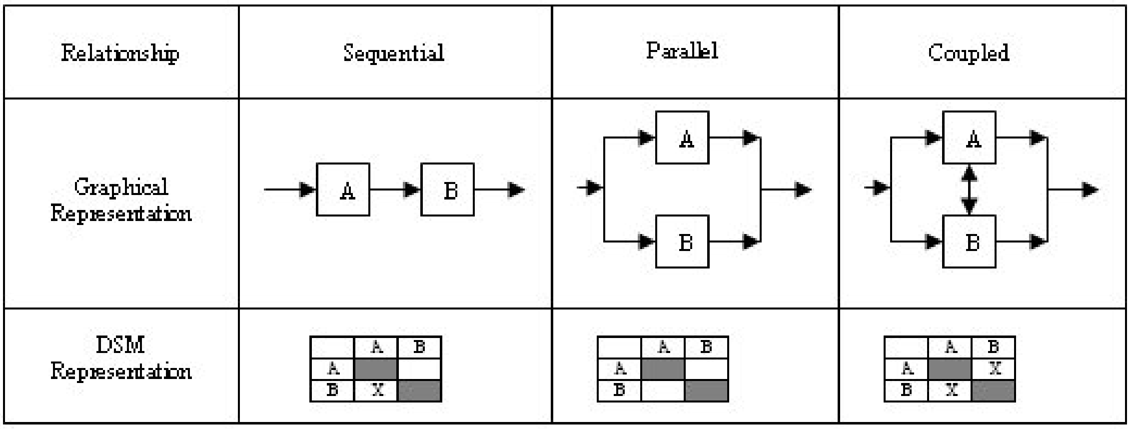


Figure 2-2: Design Structure Matrix

In DSM, there are three types of relationship between components of a system; sequential, parallel and coupled, as depicted in figure 2.2. A sequential relationship indicates that B is dependent on A (i.e. A needs to be completed before B is started), a parallel relationship indicates that A and B are independent of each other, while couple relationship shows interdependency between A and B, and can be described as a feedback relationship.

2.6.3 Quality Deployment Function

Quality function deployment (QFD), that originated in Japan in the late 1960s, is a concept and mechanism for translating the voice of customer into product features through various stages of product planning, engineering and manufacturing (Akao, 1990). Although first used by the Japanese, experiences from "Western" companies support the results of better products and production planning (Govers, 1996). Churchill (1983) further espoused that the definition of product quality to the consumer is the ability of that product to achieve the expected functions. QFD captures what product developers think would best satisfy customer requirements (Pullman, 2002).

Product and service quality can be effectively improved when the most important customer requirements are satisfied. For new product development, it is not difficult if stakeholders cooperate and share information effectively. However, for the modification of the existing product and meeting requirement changes especially when the initial QFD is developed by a designer that is no longer available, presents a challenge. QFD becomes complicated when new designers are not able to understand the rationale behind the initial QFD matrices (Myint, 2003). QFD is an approach used to guide R&D, manufacturing, and management toward the development of products and services that satisfy the needs of consumers (Trappey, 1996).

Govers (1996) suggest that Essential characteristics are: customer orientation, team approach and a way of concisely structuring communications and linking together information. QFD is used as a customer-oriented approach to facilitating product design by analysing and projecting customer requirements into product attributes (Fung R. Y. K et al., 1996). The QFD operations are performed by way of a diagram called the House of Quality (HOQ). The HOQ contains information about the customers needs (what), mechanisms to address these needs (how), and the criterion for deciding which "what" is the most important and which "how" provides the greatest customer satisfaction (Trappey, 1996). By describing the interrelationships between customer requirements (CRs) and technical attributes (TAs) of a product, and the correlation among TAs, target levels of TAs will be determined in order to achieve higher overall customer satisfaction (Fung R. Y. K et al., 1996).

QFD highlights the fact that certain engineering characteristics or design features had both positive and negative aspects. QFD also highlights the importance of starting explicitly with customer needs. QFD is more of a process than a tool for product as well as production process development based on the concept of Company Wide Quality Control (Govers, 1996). The complex relationships between customer requirements and technical attributes, and the correlation between different TAs, can be illustrated in a typical HOQ.

2.6.4 Key Observations

- Requirements decoupling is desirable, the problem with complete decoupling of product elements is that elimination of coupling in some products is not always possible. To use AD successfully, it is recommended that the initial design of a product will be done in AD.
- This research will only use the basic matrix approach in AD and DSM. DSM can also be used to improve the planning, execution and, management of complex product development projects using different algorithms (i.e., partitioning, tearing, banding, clustering, simulation, and eigenvalue analysis); these will not be covered in this thesis.

The next section reviews modelling techniques that can be used to represent a relevant data extraction methodology (chapter 5) and a cost impact analysis methodology developed (chapter 6).

2.7 Modelling Techniques

2.7.1 Flowchart

Flowchart diagrams are useful tools when one wishes to represent either the processing and decision logic flows within a particular process, with its associated inputs and outputs, or the flow of an entire system, with all the various types of processing, preparation, inputs, outputs, data storage media, and other hardware that are associated with it. Although used primarily for depicting the implementation flows of data processing systems, it can be useful in an environment where one has a mix of both automated and manual processes, data stores, forms, and hardware (Modell, 2003).

Flowchart diagrams that depict system flows are usually drawn in a linear fashion beginning at the top of the diagram, with a manual operation, a form, a manual input or terminal input device, or a terminator, which represents an end-user. In some cases, flowcharts may begin with a tape or disk symbol. These symbols represent input sources and are connected to other symbols that represent either manual operations or automated processing points.

Normally, these intra-process flowcharts depict each separate step and decision point in the data transformation or usage process. Decision points are usually depicted as a diamond shape with each valid condition or test result indicated as a branch from the symbol. Each branch leads to a separate processing leg or sequence of steps. These processing legs or the sequence of steps may remain separate for the remainder of the process, may join the main stream later in the processing flow, or may terminate after some error-handling procedure. In some cases, they may loop back to some earlier point in the processing flow after corrective action has been taken or to remake the decision after additional processing has occurred

2.7.2 IDEF

Information Modelling is the process of building models of the whole or part of an enterprise (e.g. process models, data models, new ontology's, etc.) from knowledge about the enterprise, previous models, and/or reference models as well as domain ontology's and model representation languages (Souchoroukov, 2004).

No complete enterprise modelling method currently exists and there is serious doubt that it will ever exist (Souchoroukov, 2004). There exists a wide range of model types, which can be used to describe aspects of an enterprise:

- **Descriptive models:** These models are very good for common under-standing and communication among people because of their informal, easy-to-grasp, syntax or formalism. Usually, they make use of diagrams comprising of boxes, circles, and arrows. Typical examples include entity-relationship diagrams (ERD), SADT (Structure Analysis and Design Technique), or IDEF (ICAM (Integrated Computer Aided Manufacturing) Definition Method) notations.
- **Formal models:** These models are expressed by means of formal description techniques (FDT) with precise syntax and semantics. Their objective is to provide rigorous system description and analysis of model properties. Examples include models written in LOTOS, Estelle, Z, EXPRESS, etc.

- **Programming models:** Indeed, any computer program is a model, which has the property of being an executable model (as opposed to others, which are at most computer process able). They must have a formal syntax and semantics formed by their underlying language, which ranges from assembler languages to conventional programming languages and to fourth-generation languages.
- **Analytical models:** These are formal models with a sound mathematical basis. They have been developed to support computations, model property analysis, or performance evaluation of systems. Examples include control models (transfer functions), differential equations, economic and physical laws, queuing networks, Petri nets, and various types of graphs. In some cases, they have an associated graphical formalism for better human understanding.

The intention of the researcher is not to review all kinds of models applicable to enterprise modelling but to present essential modelling techniques that will help him in developing the data infrastructure for cost estimation of requirement changes at the conceptual design stage.

After reviewing the literature, it was found that there is no single best methodology for presenting information models. The popular ones are IDEF0 (Integrated computer aided manufacturing Definition), IDEF3 and Unified Modelling Language (UML) (Dorador and Young, 2000). Each of these methods has their weaknesses.

IDEF0

IDEF0 is a method used to specify complete functional relationships in manufacturing environments. IDEF0 facilitates the modelling of decisions, actions and activities (Wu, 1994). IDEF0 is used to model activities and information flow. It also models the functional relationships and data that support the integration of those functions. IDEF0 abstracts away from timing, sequencing, and decision logic. This also creates its disadvantages, as IDEF0 has no time dependency so it cannot model process flows. Nevertheless, it is a powerful tool for static functional modelling (Colquhoun and W., 1991).

IDEF3

IDEF0 left a need for other methodologies able to capture the sequences of processes and information structures (Mo and Menzel, 1998). IDEF3 was created for this purpose (Mayer *et al.*, 1995). IDEF3 can describe activities and their relationships at a more required detail. IDEF3 has been introduced to model the flow of control and objects within business processes, i.e. to complement IDEF0 diagrams with a process model for the enterprise behaviour and, therefore, to supplement IDEF2. The IDEF3 process description language is essentially a diagramming language. The modelling tool for the representation of the diagram is made by KBSI software called ProSim. KBSI is a software company providing similar tools for the whole IDEF family.

- It is supported by a set of forms to collect requirements and is based on two components:
- A process flow description; and
- An object state transition network (OSTN) description. Objects are the entities manipulated by processes. IDEF3 defines an object as an abstraction of a real-world entity, which intervenes in a process description.

Process Flow Description

IDEF3 makes use of four essential types of constructs to describe processes:

- The units of behaviour (UOBs),
- Junction boxes,
- Links, and

The IDEF3 formalism, although not formally defined, is interesting because it provides the basis for a real and expressive process model. Any kind of process flow can be modelled. Cooperative activities are taken into account although described in a primitive form using relational links. One of the major strengths of IDEF3 is the description of synchronisation mechanisms, either between processes or between processes and their environment.

Information Access Diagrams

Court et al (Court *et al.*, 1995) propose a technique, Information Access Diagrams (IAD), which is used for better representation of the key information sources, and how they are used. This technique also identifies the information access routes used. IAD is based on IDEF1X. However, this method does not address business-modelling requirements; therefore, it would be necessary to combine IAD with IDEF3. The limitation is the one of IDEF1X (Zhang, 1996). IAD does however give a better understanding of what people are doing during their activities.

2.7.3 Unified Modelling Language (UML)

UML is a standard notation for the modelling of real-world objects (Fowler, 2000). It facilitates the visualisation, specification and documentation of the elements of a software system. UML offers a standard approach to perform these activities. UML has received broad industry support since its introduction in 1997. UML is a standard modelling language, used nowadays for computer software systems. Although the language is new, it has already become quite dominant and the number of tools that implements the activities of UML is growing rapidly. The language has gained even more strength when it was realised that UML is also suitable for business modelling (Eriksson and Penker, 2000, Fowler, 2000). UML modelling centres around nine predefined diagrams: Class diagram, Object diagram, Statechart diagram, Activity diagram, Sequence diagram, Collaboration diagram, Use-case diagram, Component diagram, and Deployment diagram. These diagrams provide an extensive set of notational elements for different needs. In the context of information modelling, the correct definition of class diagrams is most critical (Zhao, 1999, Dorador and Young, 2000).

Nonetheless, UML is not without disadvantages, although UML reflects some of the best object-orientated modelling practices; one of these is that UML does not offer semantics precise enough for all uses. The use of UML in nontrivial development projects can be problematic. For example, the UML group is researching more precise semantics for the UML.

2.7.4 Entity Relationship Model

One of the newest modelling techniques, and one of the most powerful is the entity-relationship model, or entity-relationship diagram, which is the modelling technique employed by the Entity-Relationship approach to analysis and design. The majority of the current literature references concentrate on the associated modelling technique, which is the heart of the methodology. Moreover, these references concentrate on using the approach for building data models. These data models because of their orientation are uniquely suited to the development of database logical models in the hierarchic, network, and relational environments. The entity is equally suited to all three because of its real world approach to data (Modell, 2003).

The 1976 paper in which Dr. Peter Chen described the analytical basis for the entity-relationship approach also included a description of the modelling technique, which is an integral part of the method. The multilevel analysis portion of the entity-relationship approach produces a series of environmental definitions each one of which is accompanied by a diagrammatic representation of that level. These diagrams are simple clear pictures of the environment in terms, which any user can understand. In fact user input is an integral part of the diagram creation process.

Entity-relationship models are not data structure models. Although at their most detailed level they contain and identify data elements, they are not data processing models. They are business models, and as such, they model business environments and depict business components.

Entity-relationship diagrams (also referred to as models) consist of representations of the various levels and parts of the organization, from the strategic to the operational level. Each model of a level represents the entities and relationships from the perspective of that level, and within a level, the entity-relationship models represent the perspective of one or more particular users at that level.

2.7.5 Key Observations

- In projects involving many stakeholders (engineers, marketing, IT, logistics, etc.) flowcharts can be more beneficial that other modelling techniques. As the flowchart diagrams are simple to learn and most people are familiar with the diagrams. For the above stated reason flowcharts have been selected as a appropriate modelling technique for the methodologies in chapter 5 and chapter 6.

- Limitations in IDEFX include the facts that exception-handling mechanisms are not documented; there is no explicit handling of triggering events, and different ending statuses of a process step are not modelled, although they may influence the logic of the process flow. Time is not incorporated and resources are ignored. The model is, therefore, not suitable for simulation, but remains descriptive. Time can be easily added in the form of mean duration associated to UOBs. However, behaviour rules defined by precedence links and junction boxes are not defined in a computer-process able form.
- Although there are numerous variations of the entity-relationship approach model notation, the three basic notation components of the entity-relationship model are symbols representing an entity, a relationship between two entities, and the attributes, or descriptors, of either entities or relationships.

2.8 Gap Analysis

Cost impact analysis problems are complex due to the high dimension of uncertainty in cost estimation and its influence on the nature of the automotive industry. This poses several challenges for methodology creation and therefore forms an area of interesting research.

It is observed that there is a lack of an appropriate methodology for the cost estimation of design requirement changes:

- Existing requirements management techniques do not adequately address cost impact analysis of design requirement changes for mechanical components (Section 2.2).
- Cost impact analysis problems are complex and requires a structured methodology (Section 2.3).
- Several sectors have implemented variations of impact analysis (Section 2.4).
- Current cost estimating techniques, do not adequately estimate the cost of requirement changes, but rather full life cycle costing (Section 2.5).

- Current cost estimating tools require extensive historical data from past projects (Section 2.5).
- Requirements need to be analysed before cost impacts can be assessed appropriately (Section 2.6).
- Finally, there is a need to represent requirements for the cost impact analysis of design requirement changes (Section 2.7).

2.9 Summary

In section 2.1 the author presented the motivation for conducting a literature survey with the aid of some questions.

In section 2.2 the author explains the following topic requirements, requirements management, requirements engineering, requirements changes and constraints. Requirement changes are currently dealt with as they are proposed (ad-hoc). Lack of proper documentation of past changes (including impacted components) and lack of all stakeholder involvement in the early stages of the product development process are also factors contributing to the problem of change management. A methodology that can manage proposed changes would be of immense benefit to any automotive organisation. The automotive industry is driven by short lead time delivery; a rapid estimate will benefit the industry.

In section 2.3 the author discusses how different product and service environment view requirements change impact analysis. In particular, the software industry and aerospace industry were examined to extrapolate possible technology transfer with regards to impact analysis.

In section 2.4 the author cost impact analysis in its totality. It was observed that to date there is a lack of significant literature on cost impact of design and manufacturing requirements change within the automotive industry.

In section 2.5 the author several cost estimation tools and techniques were review. It was observed that these tools and techniques perform cost estimation on full product lifecycle. Therefore there is a need for a requirement change cost estimation approach that will not require full lifecycle cost estimation.

In section 2.6 the functional decomposition techniques were reviewed, these will allow the establishment of traceability links between requirements and design parameters.

In section 2.7 the author describes information modelling techniques in order to identify suitable technique for his study. The key observation is that the models help to understand and manage the flow of information within a complex product development environment by simplifying details. Therefore it is necessary for all business stakeholders to have a technique that is simple to learn. The technique will not need to capture an absolute picture of the business or to describe every business detail. But, rather the essential business details

In summary, the author has presented a structured account of the requirements management and cost estimation tools and techniques used by most engineering discipline. The author identified lack of research in cost estimation of requirement changes. It is his intention, as mentioned in the next section, to investigate that further and to provide a relevant data extraction methodology and a cost impact analysis methodology for the automotive industry as part of his contributions.

Another gap identified in the research literature is that cost estimation of requirement changes is ad-hoc. It is the author's intention to conduct an AS IS study (Chapter 4) that will address these issues and provide some insights to their relationship. Many other issues were highlighted suggesting areas for future research. In subsequent chapters, many of these issues are addressed.

This chapter has provided a critical review of related research. In the next chapter, the thesis outlines a research methodology to address the gaps identified through literature review

3 RESEARCH METHODOLOGY

3.1 Introduction

The literature review presented in chapter 2 reveals that there were two main gaps in existing knowledge with regards to cost estimation of design requirement changes within the automotive industry. The gaps have led to the development of the research aim, objectives, scope, and methodology. The methodology has included the issues that would enable each OEM and Tier 1 Suppliers to establish an appropriate level of integration. In order to achieve this aim, information was gathered from sources such as literature, case studies, observations, internal reports, and automotive manufacturers themselves. To fulfil the research aim and objectives, an appropriate research methodology is required. Therefore, the aim of this Chapter is:

Chapter Aim:

To identify the research methodology and techniques used to fulfil the research aim and objectives.

In Section 3.2, the research aim and objectives are defined. In Section 3.3, available research approaches are examined. Due to the exploratory nature of this research, a qualitative research approach is adopted. In Section 3.4, adopted data collection techniques are described. In Section 3.5, the criteria for evaluating the research are provided. In Section 3.6, the research methodology adopted is described in detail. In Section 3.7, the Chapter summary and key observations are provided before moving onto Chapter 4, which discusses how data, information, and knowledge were collected from the case study environment.

3.2 Research Aim and Objectives

The aim of the thesis, as stated earlier within the introduction (Chapter 1), is:

To develop a cost impact analysis methodology for design requirement change management of mechanical components within the automotive industry.

3.2.1 Objectives

To achieve the research aim, there are a number of issues to be addressed. The following summarises the research objectives:

- To identify state of the art in cost impact analysis of design requirement changes within the automotive industry and across the supply chain
- To understand how industry carry out cost estimation of design requirement changes
- To develop a relevant data extraction methodology for the analysis of the cost impact of design requirement changes for mechanical automotive systems
- To develop a methodology for cost impact analysis of design requirement changes for the automotive systems at the specification stage with the level of information available with automotive OEMs
- To demonstrate that the methodologies are generic, i.e. applicable to other mechanical automotive systems
- To develop a prototype software (proof of concept) system for the extended enterprise

3.2.2 Scope of Research

The research scope is within the mechanical design and requirements management environment. The work reported in this thesis focuses on the cost impact of requirement changes within the automotive industry, specifically on how OEMs and their Tier 1 Suppliers manage the cost estimation of requirement changes and constraints changes. The research assumes that the changes are implemented against a detailed initial design specification and engineering drawings. The success of the research is measured by the applicability of the cost impact analysis methodology and the reception of the automotive industry to the observations from the research. The research is generic in the context of mechanical systems of a car.

3.2.3 Research Questions

This research is within the remit of the automotive industry, with emphasis on complex mechanical design systems, e.g. brakes, seating, body-in-white, cooling, etc.

The research investigates the cost impact analysis of design requirement changes on the automotive extended enterprise. The research endeavours to answer the following questions:

- How to extract a list of requirements, design parameters and constraints from experts, existing drawings and related design documents?
- Is it possible to capture the relationships between requirements and design parameters from OEM and their Supplier's perspective?
- Is it possible to predict additional cost of a proposed change using existing design knowledge?
- How could we deal with impact within a system and between systems for a requirements change cost prediction?

3.3 Research Methods

Research generally have two main approaches, namely the fixed and flexible (Robson, 2002), scientific and naturalistic (Galliers, 1992) or quantitative and qualitative (Gummesson, 1991, Burns, 2000). Qualitative research is based on an investigative approach, where most of the data collected is through interviews, surveys, and observation and is in the form of words (Robson, 2002). Qualitative researchers tend to be personally involved with their study, as a result, the research questions and design tends to 'evolve' over time as more information is collected. Sociologists, psychologists, anthropologists and recently business and industry, tend to use a qualitative research approach (Gummesson, 1991). No single methodology is capable of answering all questions and providing insights on all issues (Burns, 2000), and so both approaches are of equal relevance when conducting research.

3.3.1 Quantitative Research

Quantitative research methods are built upon a foundation of premises and beliefs, including the assumption that data must yield proof or strong confirmation of a theory or hypothesis in a research setting. Burns (2000) espouse that the most important characteristics of scientific research are control, operational definition, replication, and hypothesis testing. Control provides unequivocal answers to identify why something happens, what causes some event, or under what conditions an event occurs. Operational definition means that term must be defined by the steps or operations used to measure them. Replication means that data obtained in an experiment is reliable, such that identical results must be found if the study is repeated. Hypotheses are systematically created and subject to empirical tests.

3.3.2 Qualitative Research

Gerson and Horowitz (2002) state that qualitative research always involves some kind of direct encounter with the 'world', whether it takes the form of ongoing daily life or interactions with a selected group. They suggest that the qualitative researcher is concerned not only with objectively measurable 'facts' or 'events', but also with the ways that people construct, interpret, and give meanings to these experiences. Furthermore, qualitative approaches typically include attention to dynamic processes rather than, or in addition to, static categories, and they aim to discover or develop new concepts rather than imposing preconceived categories on the people and events they observe. Table 3-1 illustrates the main strengths and weaknesses of quantitative and qualitative research.

Table 3-1: Strengths and Weaknesses of Quantitative and Qualitative Research

Approach	Strengths	Weaknesses
Quantitative	1. Results are replicable	1. Removed from everyday life
	2. Results are verifiable	2. Difficult to respond to environmental forces
	3. Offers control and precision	3. Does not account for people's unique experiences
	4. Illustrates causal effects	4. Lacks flexibility
Qualitative	1. Direct encounter with world	1. Time required in research setting
	2. Allows unique experiences to be taken into account	2. Problems with validity and reliability
	3. Studies objects in entirety	3. Problems of anonymity
	4. Contact with participants	4. Possible bias

Contexts, situations, events, conditions, and interactions cannot be replicated to any extent, nor with any confidence can generalisations be made to a wider context than the one studied. A limitation identified by Burns (2000) is that the researcher needs to spend a considerable amount of time in the research setting in order to examine the interactions, reactions, and activities of subjects. Parlett (1975) argues that the intimacy of participant-observer relationships within the setting means that the researcher's mere presence will have profound reactive effects on the subjects of the study. As a result, the promise of anonymity, which often serves as the basis for trust, together with the requirement of authenticity, makes the researcher's task difficult in terms of the preparation and presentation of results. Possible bias, from the viewpoints of both the researcher and participants, must also be identified and elucidated.

3.3.3 Research Methodology Selection

Due to the qualitative nature of the research, the 'Template Approach' (Robson 2002, pg 458) was used to analyse data. Knowledge was captured using the questionnaire technique. A series of probing questions helped to capture an exhaustive view of the current product development process, including change management. A series of semi-structured interviews was conducted and recorded at both OEM and Tier 1 Suppler offices. The interviewees were from various departments (development, design, purchasing, commercial, IT, QA, trim cover) and expertise. Design documents were also provided where necessary. Some of the design documents provided were design notes, change request notes, process definition documents, test report sheets and a list of in-house abbreviations. The data collected was transcribed and analysed, a flowchart was also developed.

The focus of the questionnaire was:

- To ascertain the requirements and constraints management process:
- To identify bottlenecks and problems encounter on a day-to-day bases in relation to how specifications received from OEM are managed
- To identify how impact of requirements, design and manufacturing changes are managed, including change management procedures within tier one supplier

- Areas of concern within the organisation was also identified and finally, processes and systems (including IT systems) used in-house were captured.

Figure 3-1 shows the template approach, the first point illustrates that the research foundation is established from research questions and initial data collected from both literature and industry. The second point mentions a very important key factor of a dynamic environment (like the automotive industry); this involves templates for data analysis, going through each transcript and identifying processes and links between the identified processes. The third point notes the fact that practical evidence of finding are identified. Finally, results of the data analysis were presented using flowcharts and matrices.

Template approaches:

- Key codes are determined either on an a priori basis (e.g. derived from theory or research questions) or from an initial read of the data.
- These codes then serve as a template (or 'bins') for data analysis, the template may be changed as analysis continues.
- Text segments, which are empirical evidence for template categories, are identified.
- Typified by *matrix analysis*, where descriptive summaries of the text segments are supplemented by matrices, network maps, flowcharts and diagrams.

Figure 3-1: Qualitative Analysis, Template Approach (Robson 2002, pg458)

3.4 Data Collection

The main techniques used by qualitative researchers for data collection are surveys, literature review, and interviewing. Robson (1993) argues that surveys are inappropriate for producing real world experience, and so offer few benefits to research that must be relevant to an industrial setting. Moreover, surveys are not well suited to carrying out exploratory work, but are probably useful for descriptive purposes (Robson, 2002). Westbrook (1995) states that selecting an appropriate survey sample size and structure enables conclusions to be drawn that are generalisable across different firms, industries or countries. However, he also argues that surveys often provide too little opportunity for dialogue to discover what questions should have been asked but were not. Remenyi (1995) supports these views, arguing that data collected through surveys are often regarded as being superficial when compared to that collected from alternative techniques such as interviews and case studies. Based on these arguments, the survey approach was not used. Literature review and interviewing were the data collection techniques used.

3.4.1 Literature Review

Burns (2000), states that the literature review is a stimulus for thinking. He further explained that the literature review is not a way of summarising the previous work in the area, which can narrow the researcher focus to only considering existing concepts and conceptual schemes. He argues that new findings cannot always be fitted into existing categories and concepts, and that the qualitative method encourages other ways of looking at the data. The literature review should be a sounding board for ideas, as well as for finding out what is already known and what specific methodologies have been used.

3.4.2 Interview

Marshall and Rossman (1989) suggest that the appropriateness of interviewing on a particular project can be considered in terms of the strengths and weaknesses of this form of data collection. Robson (2002), states that the interview is a flexible and adaptable method which has the potential of providing rich material. Moreover, it is possible to modify the line of enquiry, follow up interesting responses, and investigate underlying motives in a way that other self-administered questionnaires cannot. However, he also states that the lack of standardisation raises concerns about reliability, while biases are difficult to rule out. The fact that interviewing is time consuming could also lead to a reduction in the number of persons willing to participate, which might in turn lead to biases in the sample selected. An additional problem is that it can be time consuming to analyse data obtained from the interview. Table 3-2 illustrates the main strengths and weaknesses of the interview technique.

Table 3-2: Strengths and Weaknesses of Interviewing

Strengths	Weaknesses
1. Co-operation between interviewer and interviewee	1. Limited time period available with interviewee
2. Allows knowledge construction	2. Difficulties with establishing reliability
3. Provides in-depth understanding of informant's experiences	3. Time consuming to prepare questions and analyse data
4. Flexible/adaptable	4. Possible bias

A potential problem with interviews involves designing the questions to be asked. Mason (2002) argues that a sequence of questions that is rigid, and which is devised in advance, lacks flexibility. However, she also argues that it is not possible to conduct a structure-free interview because the agendas and assumptions of both interviewer and interviewee will inevitably impose frameworks for meaningful interaction. Therefore, the question to be addressed by the researcher involves how much structure should be included within an interview. In order to answer the question, the qualitative researcher needs to consider which of the three main interviewing techniques will be used: structured (close-ended), semi-structured, and/or unstructured (open-ended).

Structured interviews have close-ended questions and are used predominantly in surveys and opinion polls. All respondents receive the same set of predetermined questions, asked in the same order so that comparisons can be made between the responses (Fontana and Frey, 1998).

Semi-structured interviews have predetermined questions, although the order, wording, and content can be modified based upon the interviewer's perception of what seems most appropriate. The approach offers greater flexibility than close-ended interviews and permits a more valid response from the informant's perception of reality.

Robson (2002) states that open-ended questions used with the unstructured approach increase flexibility and allows the researcher to go into greater depth or clear up any misunderstandings. This encourage co-operation and rapport, which allows researchers to make a positive assessment of what the respondent really believes, and sometimes produce unexpected answers. The disadvantages lie in the possibility of loss of control by the interviewer, and in the difficulty of analysing the responses.

3.5 Research Evaluation

Flick (2002) states that the problem of how to assess qualitative research has not yet been solved. One of the main problems concerns selective credibility, in which the researcher quotes only those passages obtained from interviews or observation protocols that best illustrate the characteristics of the everyday world under study. It also remains unclear how the researcher handles cases and passages that he or she believes are not so illustrative of the characteristics, or cases and passages that might even be deviant or contradictory. Therefore, the qualitative research methods including:

- Expert opinion
- Case study
- Reliability and validity
- Triangulation

3.5.1 Expert Opinion

Ince (2000) states that experts should consist of people who have studied and worked in the research area for a long time and are capable of understanding the implications of the work carried out. If possible, the expert should be familiar with the findings of other evaluations of similar programmes.

3.5.2 Case Study

Robson (2002, pg 178) defines case study as a well-established research strategy where the focus is on a case (which is interpreted very widely to include the study of an individual person, a group, a setting, an organisation, etc) in its own right, and taking its context into account. Typically a case study involves multiple methods of data collection. Case study can also include quantitative data, though qualitative data are almost invariably collected.

Robson (2002) also identifies some features that should be exhibited. Typical features:

- Selection of a single case (or a small number of related cases) of a situation, individual or group of interest or concern;
- Study of the case in its context;
- Collection of information via a range of data collection techniques including observation, interview, and documentary analysis.

3.5.3 Reliability and Validity

Validity is concerned with the degree to which a theory, model, or concept describes reality. The main threats to the validity of the research are reactivity, respondent, and researcher bias. Reactivity refers to how the research's presence may interface with the case settings. Respondent bias refers to the respondent withholding information or giving superficial response. Researcher bias relates to the preconceived ideas brought to the problem. The strategies outlined below are adopted to reduce these biases:

- Prolong involvement: The author visited the client organisation for a total period of fifteen weeks observing the seat system manufacturing process for the entire period of the PhD programme. The author also visited a cooling system manufacturing plant for a total period of 4 weeks during his final year. During this period, the author became accepted to the organisation reducing the reactivity and respondent bias.

- Triangulation: Multiple methods of data collection such as documents, interviews, participation observation, and literature reviews reduced the threats to validity.

- Audit trial: The author reduced self-bias by keeping full records of work carried out, meetings, publications, and interviews.

- Peer debriefing and support: The author worked extensively with industrial and academic supervisors to debrief and collate ideas after meetings, and workshops within research settings. This also reduced researcher bias.

3.5.4 Triangulation

Robson (2002), states that triangulation is a valuable and widely used strategy that involves the use of multiple sources to enhance the rigour of the research. Bryman (2005) describes triangulation as the use of more than one approach to the investigation of a research question in order to enhance confidence in the ensuing findings. Triangulation is sometimes used to refer to all instances in which two or more research methods are employed. Thus, it might be used to refer to multi method research in which a quantitative and a qualitative research method are combined to provide a more complete set of findings than could be arrived at through the administration of one of the methods alone .

3.6 Research Methodology Adopted

Based on the research choices made, and developing an understanding of the issues related to undertaking a qualitative case-study research strategy, a research methodology is proposed in Figure 3-2. The research methodology is divided into three phases namely: 1) research strategy development 2) data collection and idea formation 3) data analysis and validation.

3.6.1 Research Strategy Development

There are two main research strategies quantitative and qualitative as explained in chapter 2. Qualitative research strategy was chosen due to the nature of the research. This involves the use of case studies to create and validate novel solutions. Quantitative strategy requires subjective interpretations by the researcher, hence introducing bias into the research. Strategies for reducing bias are explained in section 3.5.3.

3.6.2 Data Collection and Idea Formation

Data was collected from two main sources, 1) publications from various journals, conferences and reports, 2) industrial observations. Two OEMs, three Tier 1 Suppliers and two Tier 2 Suppliers were contacted for the industrial observation.

The purpose of the literature review was to identify academic practices in design requirements change management. The subject area included requirements management, impact analysis, cost estimation and functional decomposition in various environments including software and hardware industries. The survey provided a broad understanding of the existing research, analysis of the strength and weaknesses of different approaches, including identification of gaps in the existing body of knowledge, as explained in chapter 2.

In order to verify that the gaps identified in the literature are consistent with the issues in industry. A semi-structured questionnaire was used to collect current practice data and an AS-IS model was created. The AS-IS model was developed to identify bottlenecks in the current practice, as discussed in chapter 4. The AS-IS model was used as the basis for the relevant data extraction methodology in chapter 5 and the cost impact analysis methodology in chapter 6.

3.6.3 Data Analysis and Validation

Matrixes and rules based approaches were used to analyse data. Case study validation was performed. It was observed that the identification of requirements, design parameters and their constraints from existing design documents posed enormous challenges. Since Engineers can find it difficult to articulate the relationships between requirements and design parameters. This has lead to the creation of a 'relevant data extraction methodology' (REXTRAM), discussed in chapter 5.

The literature review identified a number of gaps in the existing body of knowledge. The two main gaps were the limitation of 1) the existing requirements management tools and techniques, and 2) the existing cost estimation tools and techniques, both do not handle the cost estimation of requirements changes adequately.

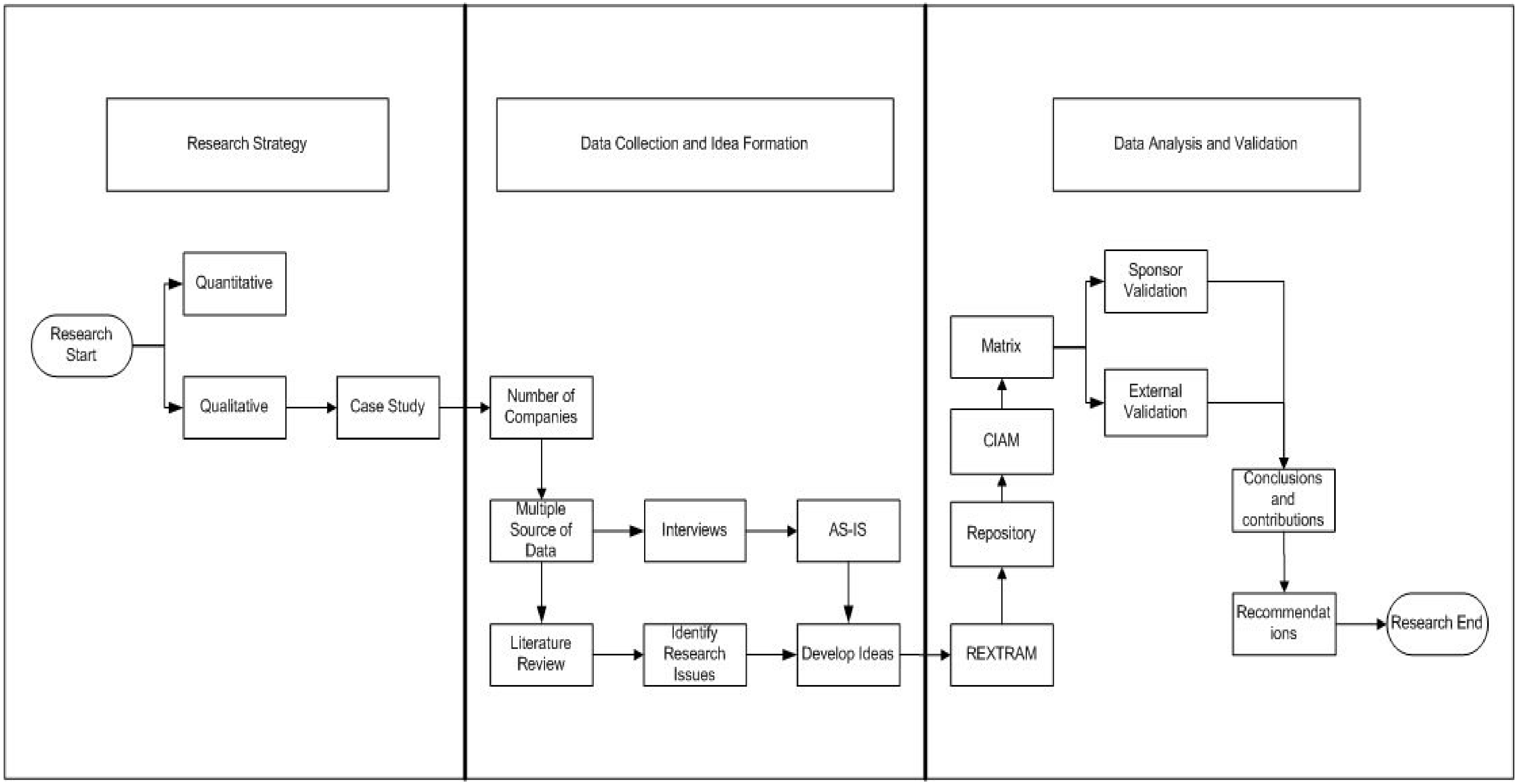


Figure 3-2: Research Methodology

This has lead to the creation of a second methodology 'cost impact analysis methodology' (CIAM), discussed in chapter 6.

Finally, a second case study was used to validate the usability and effectiveness of the methodologies. To test the generality of the methodologies, they were validated by another automotive mechanical component. The results are discussed in chapter 7. A proof of concept prototype software is presented in chapter 8. The research contributions, conclusions and recommendations are discussed in chapter 9.

3.7 Summary

This chapter has discussed the methodology that has guided this research. In section 3.2 the aim, objectives and scope of the research were set. To fulfil the research objectives an appropriate research strategy was designed. In section 3.3, the strength and weaknesses of qualitative and quantitative approaches were discussed. A qualitative research approach was chosen due to the exploratory nature of the research. The most appropriate qualitative research strategy for the initial stage was the interview approach due to the level of operational details the researcher required. The case study approach was then chosen, mainly due to the fact that the research was industrially sponsored. In section 3.4, data collection approach was discussed. In section 3.5, research evaluation was illustrated. In section 3.6, to fulfil the research objectives an appropriate research methodology was adopted. This provided a research plan, which highlighted how risks to research validity could be countered e.g. using multiple sources of data collection and involving experts from other cost estimation domains during the development and testing of the research findings.

In the next chapter, the findings of the observations in interactions between OEMs and suppliers are presented. Data, information and other relevant issues collected from the case study environment are presented. The structured approaches to data collection, such as process modelling and participant observation, lead to the identification of the bottlenecks. This aided the understanding of how OEMs and suppliers conducted requirements change management.

4 ANALYSIS OF REQUIREMENTS MANAGEMENT: CASE STUDY

4.1 Introduction

In Chapter 3, the research aim and objectives were defined, and a research methodology presented. A case-study research strategy was chosen to be the most appropriate to fulfil the thesis aim and objectives. Within this chapter, the author discusses the current practice (AS-IS) conducted with the use of questionnaires and semi-structured interviews.

In Chapter 3 (Research Methodology), the author states his assumption that impact analysis of design requirement changes can be structured. The interviews were necessary in order to validate the hypothesis, and if true, to highlight the potential problems that may arise. Therefore, the main aim of this chapter is:

Chapter Aim:

To examine the current design requirements change management practice for cost and time impact within an automotive.

The rest of this chapter is structured as follows. In section 4.2 the author discusses how the current practice was modelled and the knowledge elicitation questionnaire was developed for design requirement change management. In section 4.3 the design of the current practice model and results of the study are presented. Section 4.4 presents the difference between OEMs and Suppliers. Section 4.5 presents the difference between automotive and aerospace current practices. Section 4.6 provides key observations. Finally, the chapter is summarised in section 4.7.

4.2 AS-IS Research Methodology

This section outlines the design-requirement change management process between an OEM and a Tier 1 Supplier for their product development process. As part of the research requirements for the e-RM project, one of the agreed deliverables is the current practice model of the sponsoring companies with respect to design requirements, product development, modelling activities, interaction between key business units and change management. The output of this model is a flowchart representation of the current process. The Tier 1 Supplier (herein referred to as Supplier) is a car system manufacturer involved in design, development and manufacturing works. The Supplier's usually have offices round the world and supply more than one OEM.

The e-RM researchers from Cranfield as illustrated in section 1.1.1 conducted a series of interviews in both the OEM and the Supplier's organisation. Questionnaire were used to extract information exhaustively on the current practice within both organisations, with a view of understanding bottlenecks and constraints, problems, limitations and weaknesses of current processes. Although the interviews were conducted together, the analysis of data was done separately. The questionnaires elicited information on:

- How requirements are currently managed?
- How specifications are decomposed and allocated?
- How requirement changes are managed?
- How impacts (cost, lead time and resources) of change are managed?
- How improvement can be incorporated into current practices (discussed in Chapter 5)?

This chapter highlights areas of concern within the collaborating organisation's current operating practices, i.e. bottlenecks and constraints.

4.2.1 Why Flowchart Process Modelling?

A flowchart gives a pictorial "step by step" presentation of a process or activity. It clarifies where key decisions are made and identifies the relationship between each element in the process. A flowchart looks not only at "whom", but also "what", "why" and "how" an activity or process is accomplished. It is an important process mapping tool to use during the design phase of a process reengineering project because it is a means of understanding current business process through creation of "AS-IS" models and a means of designing new and improved processes through creation of "TO-BE" models.

During the first e-RM project review meeting, two process modelling techniques were presented to the stakeholders IDEF0 and flowchart. A unanimous decision was made by all stakeholders, to adopt flowchart for the representations. This was due to a lack of understanding of IDEF0 on the part of the Suppliers. It was considered unnecessary to retrain the collaborators as this will take time and will not add value to their day-to-day activities outside the e-RM project.

4.2.2 Data Collection

This chapter details an AS-IS study for the automotive industry with emphasis on the early design phase. An exhaustive investigation was conducted into the subject being outlined in order to present it accurately. Resource constraint contributed to the fact that all companies examined were either UK founded, or the UK branch of an international organisation.

Thirty interviews were conducted for this study, involving experts of varying knowledge and experience from eight organisations.

- Three OEMs
- Three Tier 1 Suppliers, and
- Two Tier 2 Suppliers.

In the next section the author describes the steps taken to complete the AS-IS model.

4.2.3 Questionnaire Development

The questionnaire was developed in order to test the hypothesis of this thesis. The hypothesis as stated earlier is that there is a lack of structure for the assessment of impacts (cost and time) of requirement changes within the automotive industry at the early design phase. The objectives of the interviews are:

1. To identifying issues that exists between OEMs and Tier 1 Supplier across the broad field of 'requirement changes';
2. To help identify the process and documents requirements to conduct a cost impact analysis (more information in Chapter 5), and;

Appendix A illustrates the major parts of the questionnaire:

1. Management of Requirements
2. Bottlenecks and Problems
3. Management of Changes
4. Requirements Translation/Decomposition, and
5. IT Infrastructure

Pilot Validation of Questionnaire

The e-RM team and the collaborating automotive organisation validated the questionnaire. The e-RM team reviewed the questionnaire in order to check its relevance to the research topic. The collaborating organisations reviewed the questionnaires and some experts suggested some changes, sections of the introduction and the layout of the questionnaire were modified accordingly, until a satisfactory version was produced.

Audience

The first OEM is one of the project sponsors, the second and third OEMs were contacted by conducting a ten minutes introductory presentation at their site. The author followed a team of Cranfield researcher to the second and third OEM, were he requested for a ten minutes opportunity to present his research. Both OEMs were immediately drawn to the research and requested subsequent meetings.

The first Tier 1 Supplier is also one of the sponsors of this research. The second Tier 1 Supplier got involved via the sponsoring OEM. The third Tier 1 Supplier works directly with the second OEM. All Tier 1 Suppliers mentioned that the benefits of the research to their organisation would facilitate a quick response to change request management process. It was also pointed out that the establishment of relationships between requirements, design parameters and constraints will improve the work of designers when requirements change impact analysis is been conducted.

The Tier 2 Suppliers were contacted through the sponsoring Tier 1 Supplier. The research was presented to them, although the research was not directly related to both Tier 2 Suppliers, since they do not have much influence on the design of the product. However, both Tier 2 Suppliers mentioned that the potential benefits of this research can be applied in there organisations.

Interviews were conducted on how a major OEM and tier one suppliers manage requirements. The interviewees were design engineers, development engineers, accounts, production, materials, purchasing QA and test engineers. This group is sometimes referred to as the integrated product team (IPT) or simultaneous development team (SDT). From the interviews, it was observed that costing of impact is measured by experience of experts; none of the interviewees uses any specific tool for handling cost, resource and time impact of design requirements changes.

The number of people interviewed per company, varied from between one and three individuals. These specialists, though varied in skill, were in general selected from an experienced section of the workforce under examination. To convey the type of personnel from whom the data was procured, a selection of the interviewees is listed, with job title, number of years in company and costing background (Table 4-1).

Questionnaire and interview techniques were selected as the preferred data collection approach to determine the current practice. A request was made to select automotive industrial collaborators for participant design engineers, cost estimators, purchasing staff (procurement staff), project managers and product specialists. After several visits to the industrial collaborators and an initial literature survey, questions relating to requirements management and cost estimation process were developed (Oduguwa *et al.*, 2004). Data was analysed by drawing flow diagrams of current practice with regards to requirement change management process. AS-IS model and document was produced. Workshops were held to collect design change data, to collect design documents and validate the AS-IS model.

Table 4-1: List of Interviewees

	Type of Organisation	Position	Years of Experience
1	OEM	Safety Systems Design & Test Engineer	11
2	OEM	Homologation Officer	14
3	OEM	Product Development Engineer	5
4	OEM	Product Development Engineer	10
5	OEM	Interior Trim Manager	2
6	OEM	Knowledge Management	6
7	OEM	Market & Percived Quality Engineer	12
8	OEM	Development Purchase Engineer	15
9	OEM	Knowledge Management	10
10	OEM	Project Estimator	2
11	OEM	Design Engineer	4
12	OEM	Project Manager	1
13	OEM	Project Manager	1
14	Tier 1 Supplier	Design Manager	7
15	Tier 1 Supplier	CAD Administrator	3
16	Tier 1 Supplier	Development Manager	8
17	Tier 1 Supplier	Project Cost Manager	5
18	Tier 1 Supplier	Purchasing Manager	5
19	Tier 1 Supplier	QA Technical Administrator	4
20	Tier 1 Supplier	QA Engineer	2
21	Tier 1 Supplier	QA Lead Engineer	3
22	Tier 1 Supplier	Project Manager	6
23	Tier 1 Supplier	Engineering Systems Manager	6
24	Tier 1 Supplier	Account Manager	4
25	Tier 1 Supplier	Account Manager	3
26	Tier 2 Supplier	Prject Manager	2
27	Tier 2 Supplier	Technical Manager	3
28	Tier 2 Supplier	Business Development Manager	2
29	Tier 2 Supplier	Senior Engineer	5
30	Tier 2 Supplier	Engineering Manager	2

4.2.4 Conducting the Interviews

The researcher opted for a semi-structured interview approach. This enabled the researcher to define the depth of answers provided for different questions and the amount of time and attention given to different topics. This series of interviews was conducted together with the other research member (Dr Clive Kerr and Miss

Chrysanthy Makri) of the e-RM project. The analysis of those interviews was performed separately, each focusing on his/her domain of research.

The primary function of the questionnaire (Appendix A) was to support the principle method of knowledge elicitation, which was through personal interviews with the industrial specialists. The interviews were conducted on site, at each company location, by the researchers; they were taped and transcribed, to ensure maximum accuracy; and to utilise the information to the best detail. The interviews were conducted in order to obtain the tacit knowledge of the experts; as well as to procure the processes employed for product costing within the company.

4.2.5 Dissemination of Observations

The results of this study are summarised in the form of this chapter. Prior to publication of the final draft, a draft of this survey was initially circulated throughout the participating companies to allow necessary modification to the content and contributions, therefore validating the outcome in a workshop sessions. This report was subsequently made available to all participating organisations, plus all sponsors of the e-RM project. Due to confidentiality agreement between the companies and the authors, the findings of the survey are presented anonymously.

4.3 Design Requirements Change Management: Current Practice

In-house documents were also provided where necessary; some of the documents provided were process definition documents, test report sheets and a list of in-house abbreviations. The data collected was transcribed and analysed and a flowchart was developed. The focus of the questionnaire (Appendix A), was to ascertain the requirements and constraints management process, bottlenecks and problems encounter on a day-to-day bases in relation to how specifications received from OEM are managed, impact of design and manufacturing changes are managed, including change management procedures within the Supplier organisation. Areas of concern within the organisation was also identified and finally, processes and systems (including IT systems) used in-house were captured. The recorded interviews were transcribed and then analysed using schematic diagrams—flowcharts.

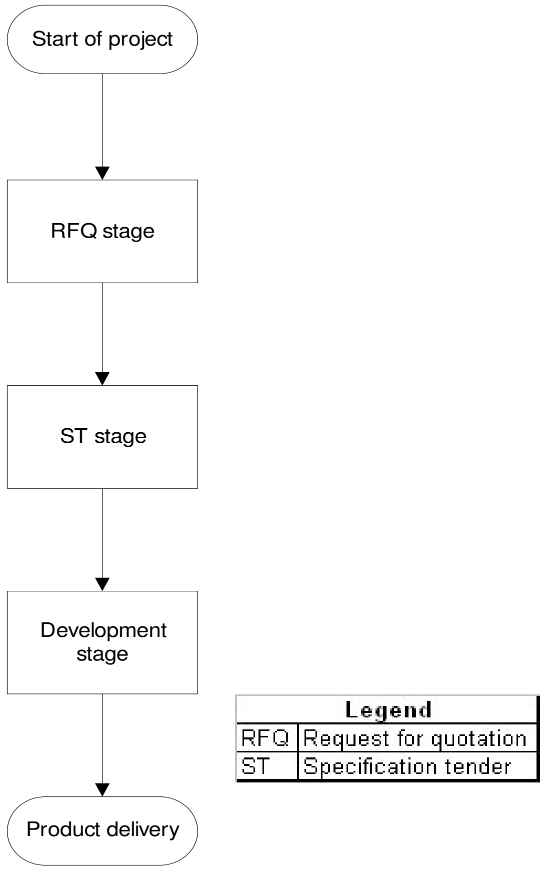


Figure 4-1: Generic Product Development Process

The product development process in the automotive industry can be divided into three stages (see Figure 4-1): Request for Quotation (RFQ), Product Specification and Development stage. Each stage follows a series of iterations to refine the exact specification of the final product. At each stage OEM engineers are in constant communication with their counterpart in supplier organisations. It was observed that suppliers usually have their own product development system. These systems usually contain documentation of processes suppliers deploy for the development and manufacture of car systems i.e. Statement of Work (SOW). Section 4.3.1 to section 4.3.7 describes the process captured for the current practice (AS-IS).

4.3.1 RFQ Stage

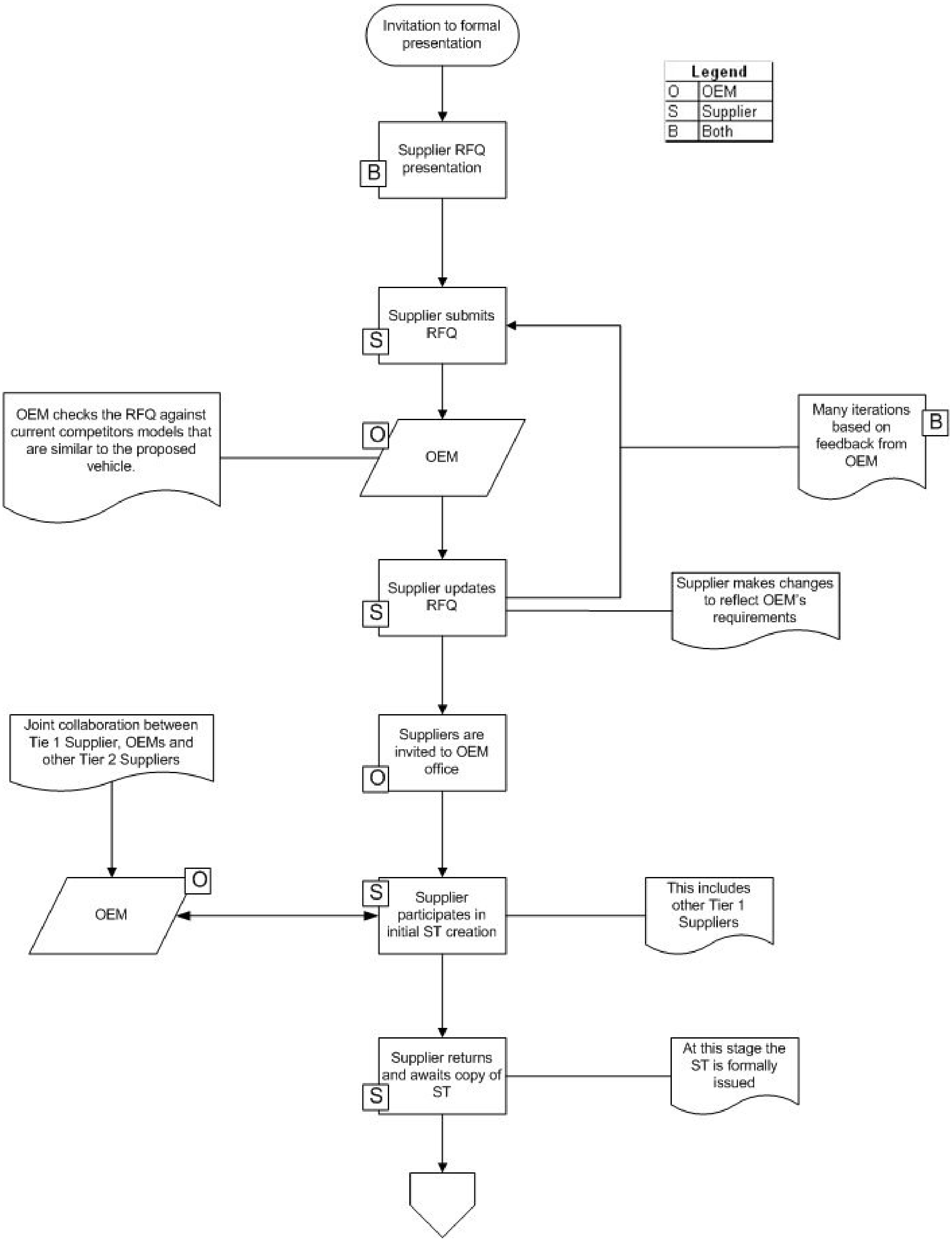


Figure 4-2: Illustration of RFQ Stage and Transition to Product Specification Document

When OEMs want to build a new vehicle (or variant of an existing model) they invite their Tier 1 Suppliers to bid (competitive tendering) for the project. Figure 4-2 illustrates the RFQ stage, this stage involves a number of iterations to refine and clarify OEM's requirements into an agreed specification, between OEM and there suppliers. The first tier suppliers are invited to a formal presentation, where OEM will inform the suppliers of there intention to build a new vehicle (or variant of an existing model).

The ensuing flowchart diagrams are further explained. The flowcharts illustrate the responsibilities of both OEMs and Tier 1 suppliers in the requirements change management process. O denotes sole OEM responsibility; S denotes sole Supplier responsibility, while B denotes joint responsibility.

The suppliers will be required to submit an RFQ and design specifications of what they understand as OEM's requirements. The suppliers go through iteration of RFQ's and OEM's selection process, before they are awarded the business (the rest of this document will assume supplier is awarded the business). At the end of the RFQ stage and selection process described above, the Tier 1 Supplier are invited to OEM office. Where they will be presented with OEM's idea of what the vehicle will look like, both OEM and the Suppliers will draw up the initial product specification document.

4.3.2 Product Specification Document Stage

Figure 4-3 shows the decomposition and dissemination of the tasks outline within the product specification document. OEM together with their suppliers draw up the initial product specification document, and copies are sent to the suppliers (packaged as an OEM document). As new ideas emerge within OEM and requirements change, subsequent product specification document will follow; some of the product specification document may contain design changes, and may have cost implications (i.e. cost impact on other part or suppliers).

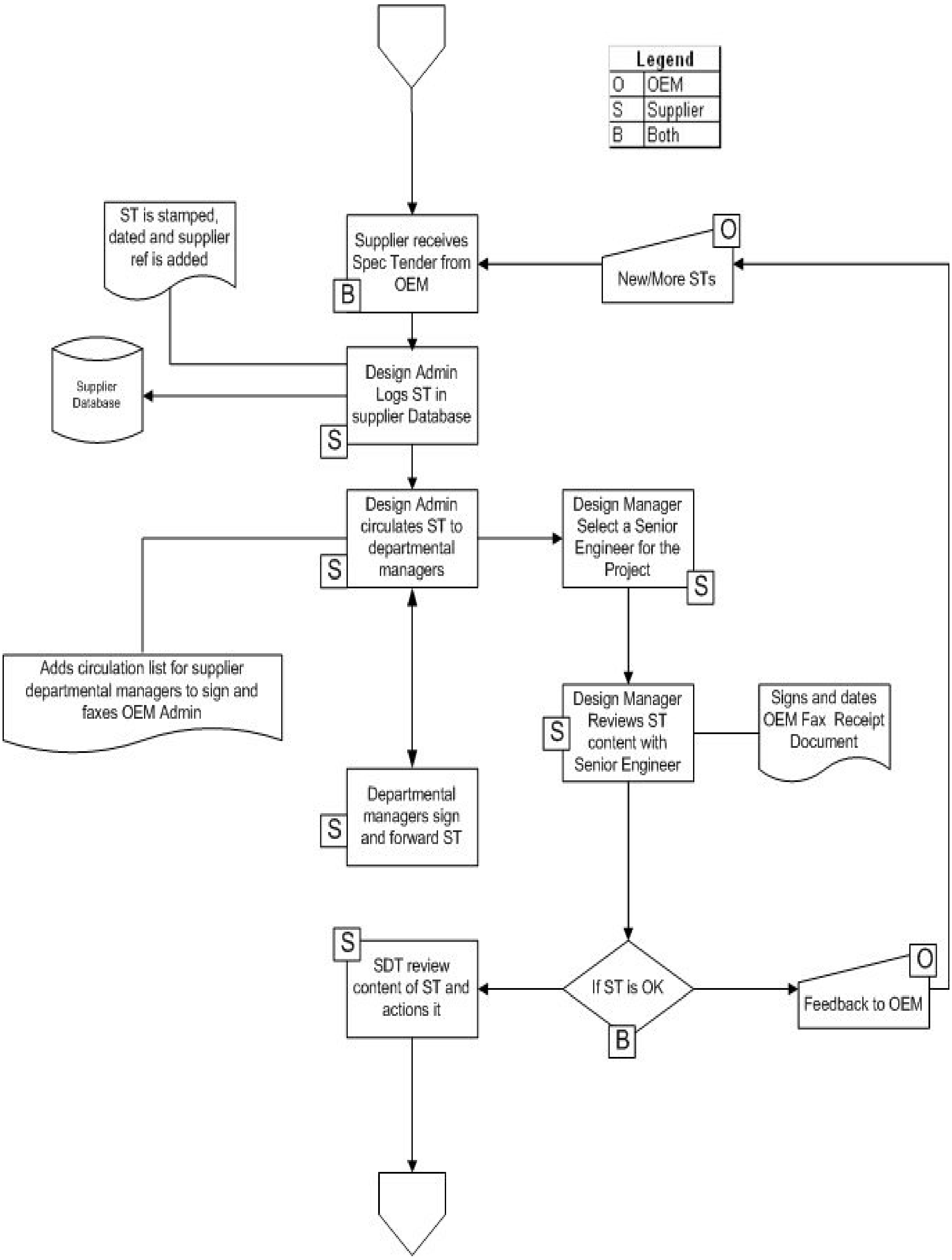


Figure 4-3: Decomposition and Dissemination of Product Specification Document

Once the Supplier receives a product specification document, the Design Administrator logs the product specification document into supplier's database, stamps, adds reference number and dates the product specification document, copies are sent to the design Manager and a senior engineer selected by the design manager (the selection is usually based on experience). Product specification document is reviewed by both design manager and the senior engineer, if they are satisfied with the content i.e. the document is as agreed with OEM prior to if been sent. The design Manager and the senior engineer sign an OEM Fax Receipt Document (FRD).

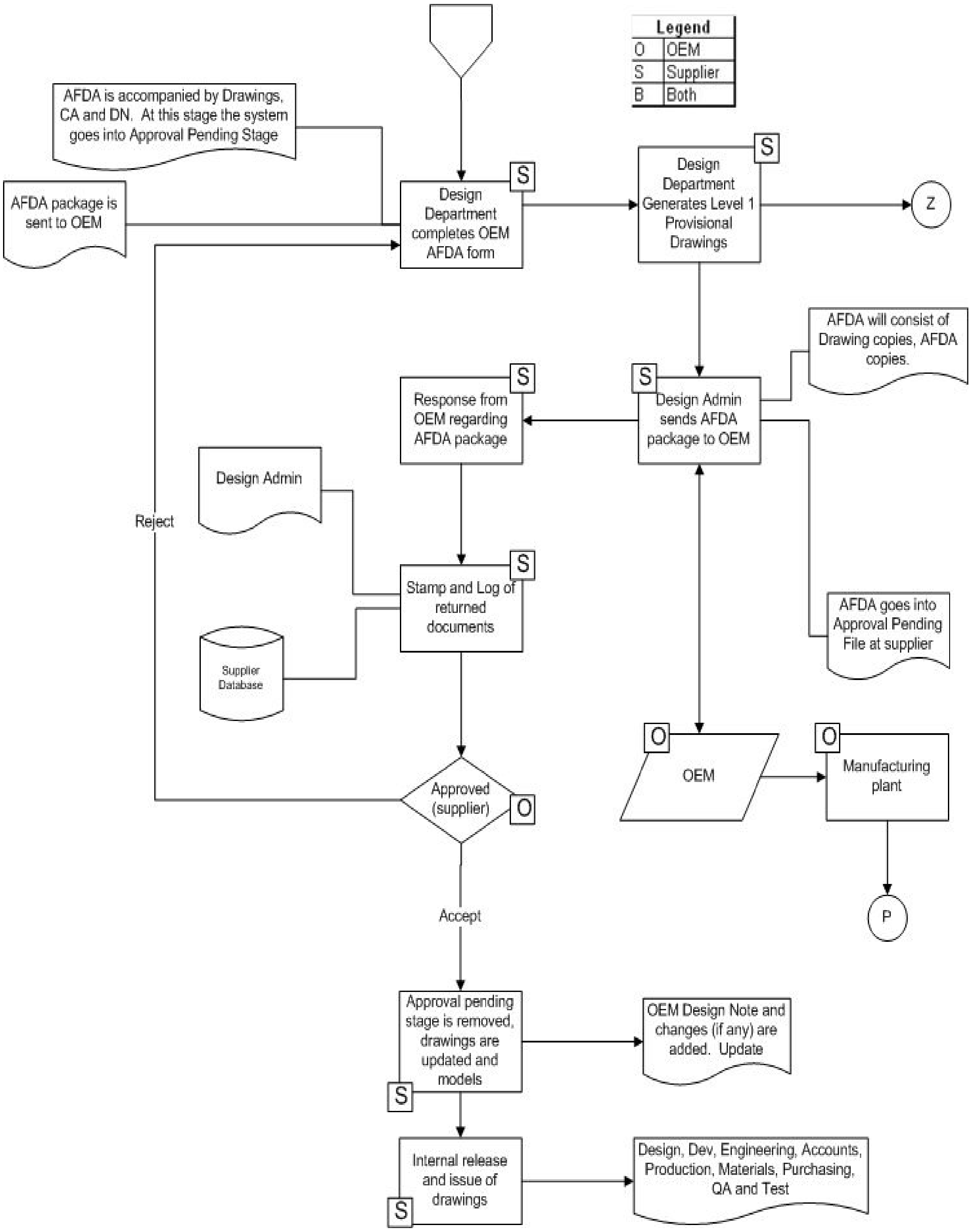


Figure 4-4: Decomposition and Dissemination of Product Specification Document (cont.)

The Design Administrator will fax the FRD to OEM, adds a circulation sheet to the product specification document and circulates it round supplier (positions of recipients of ST are on the circulation sheet). They all sign the circulation sheet and the last signatory sends the product specification document and the circulation sheet back to the design manager.

A Simultaneous Development Team (SDT) team is set up to review and action the content of the product specification document (the SDT is made up of design engineers, development engineers, accounts, production, materials, purchasing QA and test engineers). The Design Engineer generates a provisional level one drawing and completes an Application For Drawing Acceptance (AFDA) form, compiles documents (drawings and AFDA) and sends it to OEM administrator, as shown in Figure 4-4.

At this stage the project goes into an Approval Pending File (i.e. supplier awaits OEMs decision). OEM will reply with one of four options, (see Table 4-2 for possible options). OEM can reject the design if it differs from what they expect, the design can be accepted with minor changes from either sides (OEM or supplier) or OEM can accept the design without any modification.

Table 4-2: OEM Acceptance System

Options	Description
1. Cancelled	1. Rejected, needs rework
2. Accept – Accept without corrections	2. Accepted as it is, without any corrections
3. Accept – with some corrections due to OEM's mistakes	3. Mistakes are due to oversight on OEM's part
4. Accept - with some corrections due to Tier 1 Supplier mistakes	4. Mistakes are due to oversight on Tier 1 Supplier's part. OEM will score their supplier down

Supplier will receive response to application for drawing acceptance, list of drawing changes (if required) and OEM design note. Supplier's design administrator will log the documents into supplier's database. The document will have a reference number, company stamp and date. The Design Engineer signs and faxes OEM Manufacturing to confirm receipt. Supplier removes and updates the original drawings from Approval Pending File.

Supplier adds OEM design note and changes, updates and issues CAD drawings and models, design administrator releases and issue drawings, SDT reviews and approves status of the document content, and adds another circulation sheet, the documents are circulated once again. Change Notification (CN) is raised after the SDT reviews the product specification document, the Project Department is responsible for raising the CN, this confirms that the Project Department authorises the change.

4.3.3 Development Stage

Materials department will contact OEM to confirm implementation date; materials department use software tool for bills of materials, material requirements planning (MRP) and stock level handling. These tools may also handle multiple level bills of material, multiple currency and negative stocks. Purchasing department will request for quotes from second tier suppliers, the Tier 2 Suppliers will be sent transmittal note, change authorisation, design note and drawings, see Figure 4-5.

OEM sends a fax to the supplier to confirm receipt and also to confirm that the drawings comply with their internal system. However, if the OEM disagrees, the OEM and the supplier go through a negotiation period until a compromise is reached, then tooling and production will commence. The negotiation period involves several face to face meetings, the audience and the number of meetings depends on the schedule for delivery and complexity of product. Project Department now releases Change Note (CN), a copy of the CN is sent to the Purchase Manager. The Project Manager can then start the purchase process, at this stage tooling can commence if there is the need for it.

Generally all department will commence operation when a Change Note has been released by the Project Department, some parts are made in-house, however there are times when it is cheaper to order parts from abroad than it is to make them in the UK (sometimes as far as Czech republic) depending on cost. If the parts are ordered from abroad it is very important that they get it right first time, this takes time, a senior member of supplier will travel abroad to make sure the parts are as expected and within the legal requirements of the UK. The Tier 2 Suppliers will make and deliver the part they are responsible for; Supplier also makes some parts in-house.

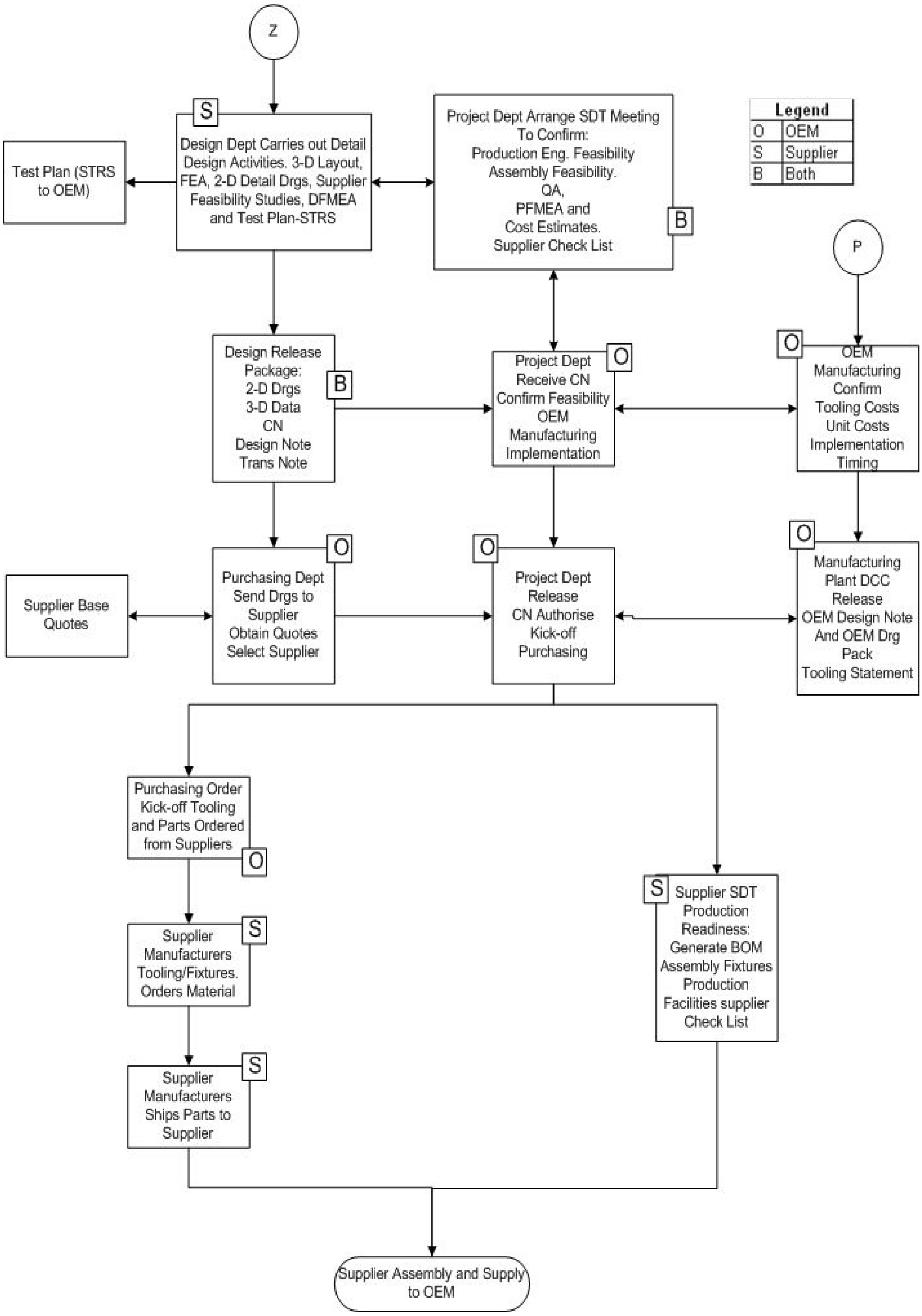


Figure 4-5: Overview of Design, Costing and Manufacturing

The test team deals with testing the longevity of the seats, they do vibration test to simulate what will happen in the car in various weather conditions and at different road situations. Quality Assurance (QA) team's duties include verification and validation of the functionality, appearance and style of seats. Testing is carried out throughout the manufacturing process. The seats are assembled and tested to see if they comply with government regulations. Approximately 150 tests are planned for each project. The OEM Specification Standard and the Safety Regulations (as agreed in Brussels and Geneva) are used as test safety standards for seats. The end product is verified for quality by an appointed Vehicle Certification Authority (VCA), the VCA is employed by OEM to certify the approval of seat quality and standard (EC regulation).

4.3.4 Design and Manufacturing Change Management

Design Changes are currently managed at Regular management meetings and by the IPT team. Typically, specification changes are communicated to Tier 1 Supplier and time impact is assessed using an in-house database called Budget form (time estimator). If OEM have a quality concern during a build, the concern is feedback to the supplier, i.e. OEM has identified a (some) quality concern, OEM and supplier agrees on what the countermeasure is with OEM.

Then OEM will release a product specification document approving the change if it is a major change. For each trial build there are about 2 or 3 product specification documents, with various build in them, and normally OEM has about 3 trial builds. For late changes suppliers sometimes commence with the build without first receiving product specification document from OEM, this is so that supplier can meet up with Start of Production (SOP) date, since there is a level of trust. Impacts of changes are discussed at in-house meeting in Supplier, meeting can be arranged in short notice, impact on cost, time and resources are discussed in such meetings.

If a major change is requested (i.e. spare part components that affects OEM process), which will mean the spare parts for the vehicle will no longer be suitable, it will not fit anymore, in cases like this supplier will have to go through the acceptance system shown in Table 4-2. For internal change, Supplier does not need the acceptance system. OEM sends back the acceptance documents to JCA and at the same time OEM sends design notes (DN) to OEM's Design Changes Control department (DCC). OEM is responsible for making sure the changes are implemented.

At this point supplier's design work finishes, once a DN is release and suppliers have made the changes, supplier adds the DN to the drawings makes the corrections and issues it. OEM's DCC will control the implementation-contacting Supplier's Material Handling department to confirm an implementation date. Once that date is confirmed with OEM, OEM will release an official document to supplier. Supplier Material Handling Department is required to sign confirming that Supplier accepts the implementation date. There is close co-ordination between OEM's DCC and supplier's Control department to make sure the change goes in, right down to the particular vehicle, on a particular shift and on a particular date.

4.3.5 Cost Estimation Process (Tier 1 Supplier)

The selection is based on a best fit profile, which matches an RFQ to a Tier 2 Supplier. The BOM will contain the individual parts and the quantities required. The purchase department of the Tier 1 supplier then forwards the completed BOM the pre-selected Tier 2 Supplier. Generally, Tier 2 Suppliers are expected to return a quote with in one week of the request.

There are two types of cost estimation performed by the Tier 1 Supplier. The first is for RFQs (section 4.3.1); the Tier 1 Supplier's SDT creates a BOM for the RFQ and selects a Tier 2 Supplier from their bank of Tier 2 Suppliers. Figure 3 illustrates the cost estimation process, the process involves the cost estimators and design engineers creation of the bill of materials, and at this stage the components that are needed to produce the final product are identified. The organisation has in-house Operating System documents is used to identify the components needed to achieve the final product. This information is passed to the purchasing department with the target cost; the target cost is the maximum cost that is allowed for the overall purchase.

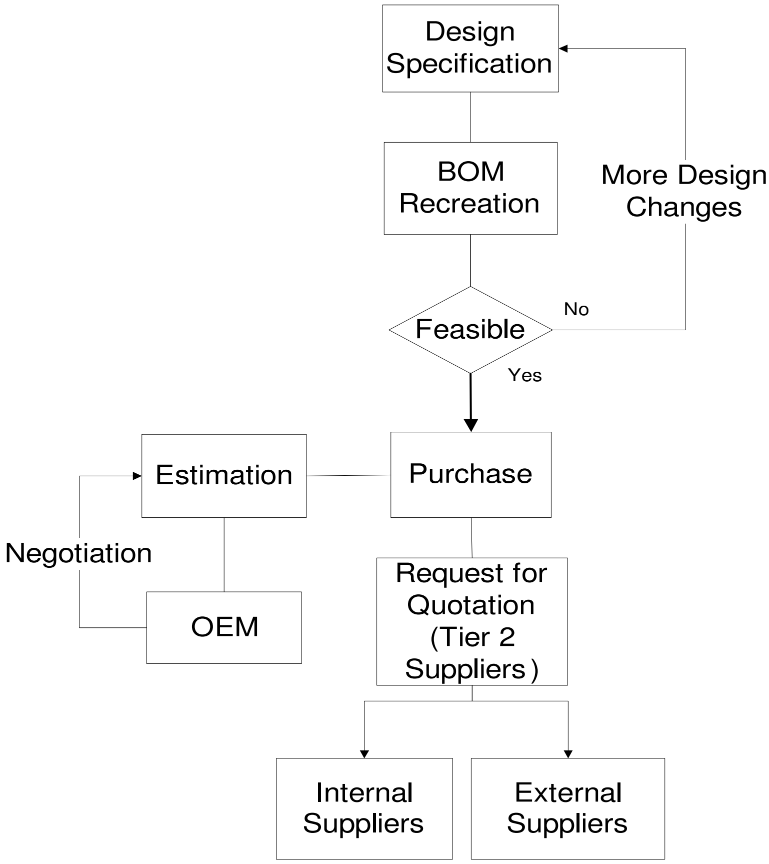


Figure 4-6: Tier 1 Supplier Cost Estimation Practice

The purchase department will then identify the suppliers, as shown in figure 3 there are 2 types of suppliers, internal supplier and external suppliers. The internal supplier supplies mostly finished components that are ready to be assembled onto the final product, while the external suppliers supply components that are reprocessed before assembling them to the final product. Again the in-house Operating System document is used to identify the external suppliers.

The purchasing department will request for quotation (including lead-times) from the Tier 2 Suppliers, the quotes are negotiated until a compromise is reached between Tier 1 Supplier and the selected Tier 2 Suppliers. Once a quote is received the commercial department of Tier 1 Suppliers then makes the necessary adjustments to the quote by adding overhead and profit. The estimators add additional costs, the additional costs are overheads, labour and development cost of engineering. This cost estimate is packaged and sent to the OEM; the next stage is referred to as the negotiation stage. This involves cost reduction exercise, where the OEM identifies items that can be removed, the supplier will have to either re-estimate or justify the importance of the component. The OEM will also shorten the lead-time; the supplier will have to justify the lead-time suggested by them (the supplier). Every design change goes through the process described above. After the negotiation stage the OEM authorises the tier 1 suppliers to commence production. The tier one suppliers in turn authorises the Tier 2 Suppliers to commence production, when the Tier 2 Suppliers delivers the component they produce, the Tier 1 Supplier assembles the product and delivers it to the OEM.

Challenges of Design Requirement Change Management

Several problems were identified with the current requirements change management approach:

1. In one of the interviews conducted the interviewee stated that "*Constraints are mainly to do with internal communication mode and circulation of critical document e.g. Specification Tender (ST). Sometimes the ST is ambiguous*" (Appendix B). The problem of ambiguity here can be attributed to approximate reasoning (Zadeh, 1965). The fundamental principle in the theory of approximate reasoning is that human reasoning for any process is imprecise and subjective due to incomplete knowledge. This can be related to the reasoning behind the creation of the ST, which is based on human reasoning. This process if not structured can be imprecise and subjective. Literature also reveals the current approaches to design requirement changes are rigorous for evaluating and comparing designs once requirements and design parameters have been clearly defined. Yet, the requirements and design parameter formulation process is not rigorously specified. A consistent theme across literature and evident in industrial observation is the failure to articulate requirements, design parameters and constraints extraction from specification documents, as corroborated by Soderborg et al., 2002, "*Whether this is even possible is debatable due to the creative element in such formulation. The use of natural language to capture and communicate requirements and design parameters further complicates the problem. Rigor calls for elimination of subjectivity and ambiguity to make it work in real life".*

2. The roundtable discussion approach to determining impact of requirement changes can lead to the omission of important effects of proposed changes. For example, if one of the key stakeholders is not present at the roundtable discussion, there is a tendency that a change affecting this key stakeholder will not be addressed until later in the product development process. The other members of the roundtable discussion cannot be expected to always know how all changes affect all stakeholders. This can be attributed to the bounded rationality issue, since the human mind is usually at its best when decisions are made in the person domain of expertise. According to the theory of bounded rationality (Simon, 1972), it is not always possible to know how the problem originating from one system would influence all other related systems. This difficulty often spread through to collaborating departments/organisational, where there is always a tendency to resort to solving local problems with little regards to how this problem affects the organisation as a whole.

Solution Strategy to Design Requirement Change Problems

The problems mentioned above can be address by introducing to novel approaches:

1. Since design changes cannot be avoided in OEM/Supplier relationships due to the interactive nature of the mechanical design process (Karlsson et al., 1998). An approach that will reduce ambiguity and subjectivity is required for the extraction of requirements and design parameters from specification documents. This approach will break down the product into a hierarchical structure. The approach will establish relationships between the components; this will aid the impact analysis identification. For example, when a change is proposed both parties (OEM and tier 1 supplier), there will be visibility of other systems and subsystems affected, including visibility of effort required to implement a proposed requirement change. This will be a relevant data collection methodology.

2. The cost estimation of the design requirement changes will require an approach that will assess the following:
    a. The cost of the proposed design requirement change,
    b. The cost of the affected components, and

c. A cumulative cost of the ripple effect of the proposed change.

This approach will be a cost impact analysis methodology, since the cost of impact analysis is calculated.

4.3.6 Observations in Tier 2 Supplier

Tier 2 Suppliers are those organisations that provide inputs to Tier 1 suppliers. The Tier 2 Suppliers tend to manufacture small parts, preassembled parts that can be fitted onto major systems. The bolsters, armrest, cooling fan, expansion tanks, radiators and electronic are examples of parts supplied by Tier 2 Suppliers.

Tier 1 Suppliers sends quotes to Tier 2 Suppliers, who usually have many Tier 1 Suppliers as customers. The expertise of the Tier 2 Supplier is typically in a specific area. Therefore, response is normally prompt, except when the Tier 1 Supplier's request is more complex than previous projects, in which case the Tier 2 Supplier request for more time to manufacture the required part.

Cost estimation is usually based on experience; there was no cost estimating package in the Tier 2 Supplier organisation visited. Cost estimation was based on in-house excel spreadsheets, created by experience engineers.

4.3.7 Validation of the Current Practice (AS-IS)

A validation workshop was organised at one of the industrial partner's office in Waverdon, Milton Keynes. The workshop was consisted of employees from the sponsoring companies (two experts from the OEM, two experts from a Tier 1 Supplier, two consultants from a software vendor and one manager from a vehicle regulatory organisation). The industrial partner's validated the observation from the research carried out by contributing to the findings of the researcher. The process of validation is as follows:

- Copies of the AS-IS report was sent to the industrial partners for confirmation of true reflection of the internal practice

- The industrial partners suggested corrections and changes to the AS-IS model. These corrections and changes were made to the document. For example, the author was under the impression that requirement changes can only be proposed by the OEM. However, a feedback from the workshop was that Tier 1 Suppliers can suggest requirement changes, but the requirement changes must not incur additional cost.
- The AS-IS report was updated and a final version was released to all industrial partners.

4.4 Difference between OEM and Supplier

In a study conducted by IBM Corporation in 2002, it was discovered that the automotive parts and accessories industry is comprised of several varieties of manufacturers. Suppliers produce automotive stampings; carburettors, pistons, piston rings, and valves; vehicular lighting equipment; storage batteries; engine electrical equipment; and motor vehicle parts and accessories.

OEMs have enacted new procurement and product development strategies in recent years to trim costs and improve quality. Suppliers benefit from increased orders from the big three automakers and also from enhanced productivity. This gain-sharing approach has worked particularly well for Ford Motor Company and DailmerChrysler. However, General Motors has been slow to implement these programs because of their greater reliance on vertical integration. The labour strike by GM workers in the summer of 1998 was a result of GM shifting production off shore for labour intensive production activities.

Several OEMs been purchased by the Big Three. Big Three operations are worldwide. Ford owns Jaguar (UK), Aston Martin (UK), BMW's Land Rover SUV (Germany) and Volvo (Sweden). Ford also has a 33% stake in Mazda (Japan). GM owns Saab (Sweden), Holden, Opel (Germany) and Vauxhall (UK). GM has a 40% stake in Isuzu (Japan), 20% in Subaru (Japan), 42% in Daewood (South Korea) and 20% stake in Fiat (Italy). DailmerChrysler produces Mercedes-Benz (Germany) cars. They have a 10% stake in Hyundai Motors (South Korea) and 37% in Mitsubishi (Japan).

Suppliers are classified within tiers to represent their position in the supply chain. The role of suppliers, along with their distribution channels continue to evolve. Suppliers have gone from producing specific parts to spec, to delivering integrated systems that they engineered. In the near future, that role will increase to include design and ownership of entire systems, including integrating lower tier suppliers and taking full warranty responsibility of their systems.

Tier 1 Suppliers typically have to work with three types of OEMs - non-sophisticated, spec providers or design partners. Non-sophisticated includes suppliers who are: Technically not very advanced, expect Tier 1 suppliers to develop and deliver to high-level specifications, examples include Korean OEMs and smaller Japanese OEMs. Spec providers are mature, technically advanced OEMs, specify detailed specs to Suppliers, expect suppliers to comply with the smallest details of these specs, examples include GM and VW. Typically these are technically advanced, jointly develop system-level specifications with suppliers, examples include Ford and DaimlerChrysler.

Tier 2 suppliers are small (as compared to Tier 1 suppliers) and are focused on specific product or processes. Tier 2 suppliers can have some interaction with OEMs but the majority of their sales are to Tier 1 suppliers. Their products or processes are used to complement the modules supplied by the Tier 1s. Tier 1 suppliers usually focus their business around major product divisions or subsystems. Competition for these parts is fierce.

The basis of competitive differentiation is different within each participant’s arena. Although, the key factors that drive the suppliers are common globally, their main priority changes by region. For instance, Japanese Suppliers work very closely with their local OEM customers.

The role of the Tier 1 supplier is constantly evolving. OEM's are expecting more from them including:

- Entire Component Systems

- Full-Service Design, Production, Assembly, Sequencing and Delivery
- Extension of JIT Manufacturing at FAO
- Product Development Partner
- Supply Chain Coordinator
- Best Practices: Design, Manufacturing, Logistics and Customer Service
- Continuous Improvement
- Responsible for Tier II and III Suppliers
- Shared Goal for Product Affordability
- Integrated Global Supply Chain
- Proactive response

4.5 Difference between Automotive and Aerospace

There are several differences between the automotive industry and the aerospace industry. Safety issues in aerospace is more important than in automotive, since possibility of an accident in the air is more fatal than on the road. Aerospace accidents are almost always fatal. The electronic sensors in the aerospace product need to have 100% reliability.

Aerospace products have longer life-cycle than automotive products; a fundamental difference is the product change cycle. "For a car this may be between 2 to 4 years. For an aircraft it could be 25 years or more. There are more regulations governing the way aerospace industry operates than those of the automotive industry. The regulations place enormous restraints on the ability to change suppliers.

Another difference between automotive and aerospace is, of course, the much smaller volumes. While car manufacturers may look to the production line for waste reduction opportunities, the aerospace industry is likely to focus on its information processes. The lean manufacturing tools, such as value stream mapping, may be the same, but the ways in which they are applied may vary greatly. For the production of military aircraft for example, where peaks in demand can be difficult to predict, lean concepts may be used to create new levels of flexibility and capacity management."

Unlike the automotive industry, the aerospace industry has less than a handful of major OEMs and few launches of new aircraft. If the plane launches without a supplier's component on board it could be 25 years before the next opportunity. As the supply base reduces, there will be more and more suppliers who miss these chances.

In the automotive industry production runs are measured in the high hundred thousands, if not millions. Fixture costs can be amortised over one million units. Tooling and fixture costs are, therefore, a much higher percentage of the final product cost in the aerospace industry than the automotive. The obvious conclusion from this is that major savings in production tooling can make a correspondingly greater contribution to reducing unit costs.

4.6 Key Observations

- There is a need for a better understanding of cost impact analysis of design requirement changes within the automotive industry across the supply chain. Since changes are often a necessary part of automotive product development
- There is a need to investigate the challenges and bottlenecks encounter when automotive organisations are carrying out cost estimation of design requirement changes
- A relevant data extraction methodology should be developed for the analysis of the cost impact of design requirement changes. Since automotive design documents do not explicitly define requirements, design parameters and constraints.
- A cost impact analysis methodology is required for cost impact analysis of design requirement changes. This methodology will allow designers to establish relationships between requirements and design parameters. The methodology will also allow cost estimators to determine incurred cost when requirement changes are proposed.
- The methodology will need to be reusable so that cost engineers will be able to create requirement change estimates faster in the future for similar products. The methodology will also need to be acceptable and satisfy both the OEMs

and the Tier 1 Suppliers.

It should be possible to develop a prototype software (proof of concept) system for the extended enterprise. This will further improve reuse of the methodologies

The author believes that by addressing the above issues he can provide a set of methodologies for the extraction of relevant data and cost impact analysis of requirements change for complex mechanical products.

Based on the above observations, the author will address in Chapter 5 the relevant data extraction methodology development and in Chapter 6 the cost impact analysis methodology development.

4.7 Summary

In section 4.1 the author explained why this current practice (AS-IS) study was necessary. Section 4.2 the proposed methodology was described, a questionnaire was developed and a semi-structure approach to the interviews was utilised. In Section 4.3 the main analysis of the study is presented. Cost estimation of design requirement change management and impact analysis were identified as the most important point of interaction between the OEM and Tier 1 Suppliers. Section 4.4 summarised some of the general findings between the OEMs and Suppliers. Section 4.5 summarised some of the general findings between the automotive and the aerospace current practices. Section 4.6 explained the final observation and main points on the finding as identified by this study. Section 4.7 summaries the chapter

In the following Chapter the data extraction methodology is presented. Multiple data collection techniques were used to identify the types of requirements and data required for cost impact analysis of requirement changes within an automotive manufacturing collaboration. The structured approach to data collection, such as semi-structured interview and data process modelling led to the identification of requirements, design parameters and constraints. This detailed analysis confirms and verifies many of the key observations deduced from the introduction (chapter 1) and the literature review in Chapter 2.

5 DATA EXTRACTION METHODOLOGY

5.1 Introduction

In chapter 4, the cost estimation of requirement changes and change impact analysis processes of the sponsoring companies were discussed. Two solution strategies were proposed 1) relevant data extraction methodology – REXTRAM and, 2) cost impact analysis methodology – CIAM for requirement changes at early design stage of automotive mechanical products. This chapter focuses on the development of relevant data extraction methodology. This is achieved by using template research approach as discussed in chapter 3. Two generic methodologies are developed using semi-structured interviews, flowchart, matrixes and cost estimation rules. The methodologies are applicable to mechanical design components within the automotive industry and they have been validated using car seat as a first case study.

Chapter Aim:

To develop a generic extraction methodology for requirements, constraints and design parameters for mechanical systems

This chapter addresses the relevant data extraction issues identified in chapter 4. For existing design there is often lack of documentation showing the requirements, corresponding constraints and design parameters, it is also not explicit when experts are asked. It is important to identify requirements (including design parameters and constraints) and their corresponding relationships. It is therefore necessary to develop a methodology that will analyse existing documents.

The rest of this chapter is structured as follows. Section 5.2 provides the motivation for the development of the extraction methodology. Section 5.3 describes the development of the extraction methodology. Section 5.4 provides an application domain analysis, where the car seating system is used as the case study and describes the validation process conducted in order to show the relevance of the methodology to mechanical systems within the automotive industry. Section 5.5 presents the key observations. In section 5.6, the author summarises the chapter, before moving onto chapter 6, where the results of the methodology is applied.

5.2 Motivation

During the interviews session described in chapter 4, it was evident that engineers find it difficult to articulate the relationships and to identify the right requirements and design solutions. Extracting requirements and their corresponding design solutions needs to be structured to reduce product development time and enhance viability of competitive sectors. The complexity involved is nontrivial, especially during the early phase of product development, given the reduced amount of information and the low level of definition of the product (Cavalieri et al., 2004).

For particular systems within the automotive industry, most engineering requirements can be extracted from associated design documents. The lack of knowledge of the underlying relationship between the requirements and their association with the design, makes it difficult for even experienced engineers to follow the requirements in their day-to-day work (Becker and Wang, 2003). An extraction process is required to understand and deal with change impact effectively; the process must be transparent and reusable.

The knowledge about a product is distributed among OEMs (original equipment manufacturer) and Suppliers. Knowledge of the product usually involves several stakeholders (e.g. designers, cost estimators) and often they are distributed across different sites. Cars are decomposed into systems: seat, body-in-white, electronics, power-train, brakes, etc (Roy *et al.*, 2004c). Tier 1 Suppliers manufacture approximately two thirds of these systems.

The application domain of the extraction methodology is in Cost Impact Analysis as illustrated in Chapter 6. Requirements, design parameters and constraints are extracted from a mirage of design documents. The extracted design requirements and design parameters are used to qualitatively assess the incurred cost of a proposed change on a design requirement for mechanical design components.

5.3 Development Relevant Data Extraction Methodology (REXTRAM)

Several authors have used requirements and design parameters in their research (Guenov and Barker, 2004, Houshmand and Jamshidnezhad, 2002, Soderborg *et al.*, 2002, Suh, 2001, Jeziorek, 2005, Eppinger *et al.*, 1994, Pimmler and Eppinger, 1994, Steward, 1981, Malmqvist, 2002, Browning, 2001, Yassine and Braha, 2003). These researchers have not included the extraction of requirements and design parameters. Well articulated sets of requirements and design solutions not only reduces ambiguity, it helps the architect develop the system, providing a means for organising elements formally, understanding relationships between design requirements, identifying critical interfaces and providing implementation solution space.

Axiomatic design provides a means of representing and decomposing higher-level design requirements and physical embodiments (called design parameters), until the creation of leaf-level design requirements and design parameters that can be implemented to construct the system according to the resulting design decision architecture (Pallaver, 2003). Axiomatic design enforces complete decoupling of elements of a component to a tree structure (Suh, 2001). However, AD does not help in analysing an existing system.

In a related research (Lee and Jeziorek, 2004) on requirements and design parameter mapping process, a structured framework to integrate system design knowledge and cost information, during requirements and design parameter mapping process is proposed. However, the link between design requirements and design parameters to product documentation are not addressed, neither is the issue of design requirements and design parameters extraction.

Although QFD is adequate for capturing and structuring requirement, QFD does not specify how to extract requirements. If an organisation followed the QFD approach, managing changes becomes easier since the initial design was done using QFD. QFD specifies WHATS (requirements) and HOWS (design parameters). The requirements and design parameter concept was further extended by relating requirements to WHATS and design parameter to HOWS (Soderborg et al., 2002). A distinction is made between function and design parameters that aligns function with the question “What is the system supposed to do?" and design parameter with "How does the system do it?" Design parameter is a "structure-behaviour" or structure-dynamics combination (Dori, 2002). However, constraints are not included in the extraction and formalisation of requirements and design parameters. Fridman et al (2000) provides another extension to axiomatic design by postulating approach for the formalisation of constraints in relation to requirements and design parameters. Here constraints are hierarchically decomposed at each level of requirements/design parameter decomposition. Again what requirements or design parameters are and how they are extracted from design documents are not articulate (Friedman et al., 2000).

In summary, there is a lack of structured process for the extraction of design requirements and design parameters for complex mechanical products at the early phase of product design. The next section proposes the novel structured process for the extraction of design requirements, design parameters, and their constraints.

5.3.1 Select Case Study

Figure 5-1 illustrates the extraction methodology REXTRAM. REXTRAM starts with the selection of an appropriate case study; this research has used mechanical components within the automotive industry. REXTRAM is validated by two case studies: seating system and the cooling system (chapter 7) for validation.

5.3.2 Domain Analysis

The next step starts with the domain analysis; this will allow the user of the methodology to have a good understanding of the product environment (if they do not already have it). The domain will typically be a car system, as depicted in chapter 1. The domain will usually be supplied by one or more Tier 1 Supplier.

5.3.3 Identify Relevant Documents

The user then identifies relevant documents for the extraction process. Chapter 2 identified that the automotive industry has a myriad of documents.

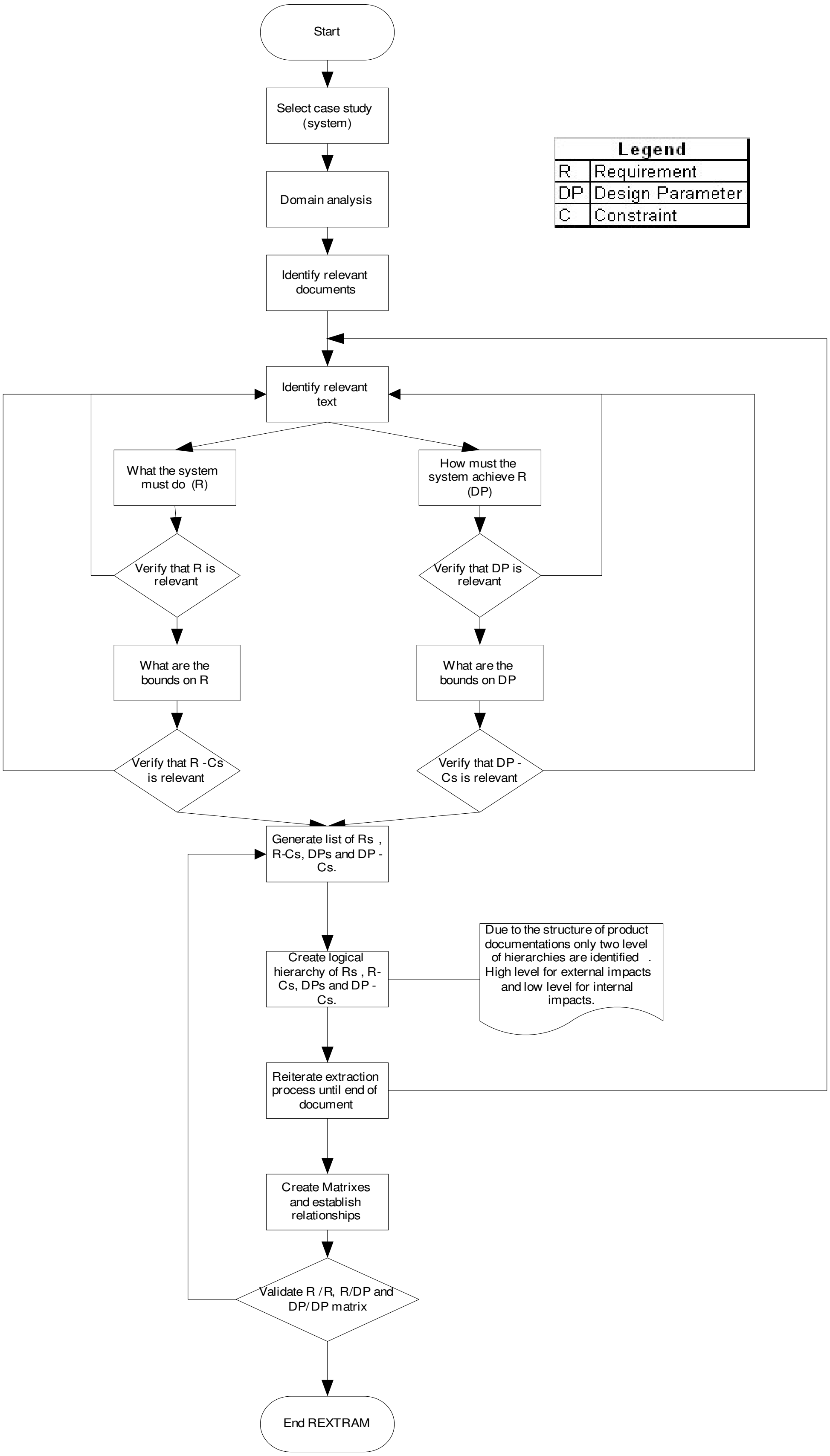


Figure 5-1: Requirements and Design Parameter Extraction Methodology (REXTRAM)

Examples of relevant document for mechanical products within the automotive industry are specification tenders, request for quotation, design change note, bill of materials, design standard, etc. The minimum document required as a relevant document is a design specification document, although different organisations have different terminology for design documents. These relevant documents are those that specify the design of the system.

5.3.4 Identify Relevant Text

Each of the identified relevant documents are manually scanned for relevant text i.e. the WHATS and the HOWS (as explained in relevant research section). The WHATS are the requirements, which are what the system must do. Constraints are identified for each requirement; both requirements and constraints are catalogued in a repository. Similarly, the HOWS are design parameters, which are how the system must achieve each requirement? Constraints are identified for each design parameter; both design parameters and constraints are catalogued in the repository.

5.3.5 Generate List of Requirements and Design Parameters

The created repository is a structured list of requirements, design parameters, and constraints. The repository includes subsystems and external impact for each requirement. The external impacts are other systems of a car that can be potentially affected by a change to a particular requirement.

5.3.6 Create Logical Hierarchy of Requirements and Design Parameters

A logical hierarchy between the requirements, requirements and constraints, design parameters, and design parameter and constraints are created, using the repository above. This will depend on the expertise of a domain engineer (design engineer in a specific car system) and a cost estimator (also in a specific car system). Two levels of hierarchy is required external system level and internal system level. These are used for external cost impact analysis and internal cost impact analysis respectively (both are discussed in chapter 6).

5.3.7 Reiteration of Extraction Process

The identified documents are exhaustively examined for relevant requirements, design parameters and constraints.

5.3.8 Create Matrixes and Establish Relationships

The repository is then used to create three types of matrix:

1. Requirements to requirements matrix (nxn)
2. Requirements to design parameters matrix (nxm) and
3. Design parameters to design parameters matrix (mxm)

It was observed that couplings exist between the entries in each of the matrixes. Uncoupled relationship between components is not always the case in most mechanical design component (Chen and Lin, 2002). A possible solution to coupling is to decouple the relationships by decomposing the requirements and design parameters further. In the automotive sector, the cost reduction exercises are constantly aimed at investigating ways of achieving multi-functional components. To have a complete uncouple relationship between requirements and design parameters of a component requires that the product must be designed initially following axiomatic design principle or similar principles that enforce decoupling. REXTRAM assumes that a product has already been designed, a cost estimate has been created and a change to the product requirement is proposed.

Create relationship matrix (requirements and design parameters)

The requirements matrix shows the relationship between requirements, how a change to one requirement will affect other requirements. The propagation path for requirement change can also be determined. The extent of the relationship between requirements is defined as Strong, Medium and Weak, as shown in Table 5-1. Strong relationship refers to situations where a new tool is required in order to compensate for the effect of a proposed change. Medium indicates that the change will only require material, while Weak indicate that the change is minor.

Table 5-1: Ranking of the Extent of Impact (Oduguwa *et al.*, 2004)

Rank	Impact
Strong	changes requiring tooling cost
Medium	changes that require modification to original tool
Weak	changes that require modifications of parts

Table 5-1 reflects the high volume mechanical parts within the automotive industry.

Stop Criteria

The requirements matrix presents a visualisation of interrelationships between requirements. Requirement changes can ripple indefinitely if not stopped. A set of stop criteria for ripple effect propagations are identified:

- Not more than 2 levels of propagation
- When a change ripples back to the proposed change origin
- When a change ripples to any requirement along the propagation path

5.4 Case Study 1: The Seating System (REXTRAM)

5.4.1 Select Case Study

The car seat is one of the most complex parts of a car. The seat is the part of a car that has the most contact with users. The seat in most cases determines the first impression of a potential customer's desire to acquire a car or not. The case study was chosen, because it offers a variety of design issues, the development of the product involves a significant number of changes before the final product is realised.

There are 3 main types of seat the driver seat, the assistant seat and the rear seat. Figure 5-2 shows the front seat, the driver and assistant seats are similar in many respect. The front passenger seat is called assistant seat. A major difference between the driver seat and the assistant seat is features. The driver seat usually has more features than the assistant seat. A typical seat is made up of headrest, backrest and seat cushion. Armrest is optional and track is usually part of the front seats.

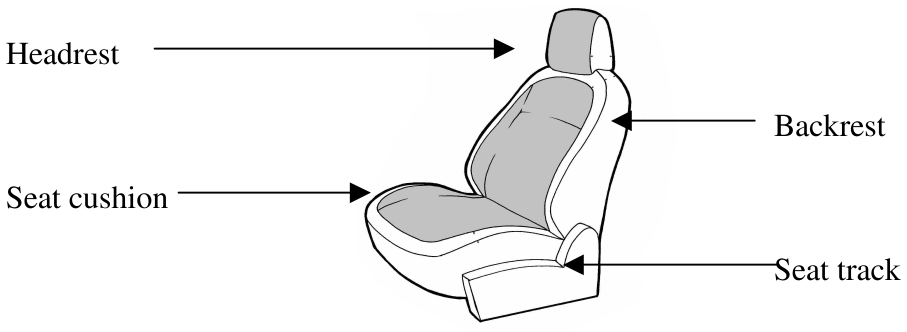


Figure 5-2: Front Car Seat (Courtesy of Johnson Controls).

The rear seat may include the second row seat and the third row seats. An added complexity to the rear seat is that the rear seat has different configurations of the backrest and cushion. The rear backrest can be single unit, 50:50 or 40:60. Similarly, the rear cushion can be single unit, 50:50 or 40:60. The 40s and 50s ratio are considered medium parts, while the 60s and single units are considered large parts. The small parts are the headrest and the armrest. The rear seats have several versions, bench or partitioned. The bench seat has single backrest and single cushion as illustrated in Figure 5-3. The rear seat can also be partitioned, usually 60:40 ratio, this allows one-half to be folded while a passenger is sitting on the other half. Figure 5-4 is an example of partitioned rear seat.

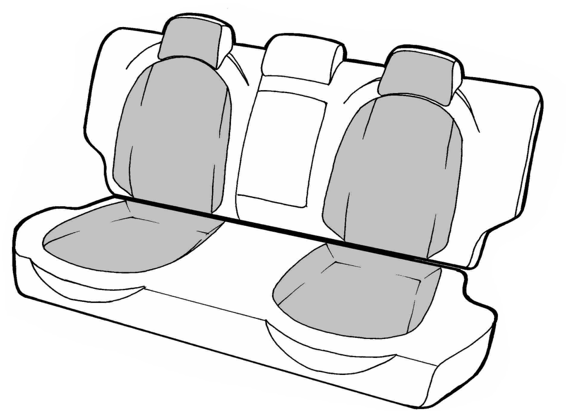


Figure 5-3: Rear Seat Bench

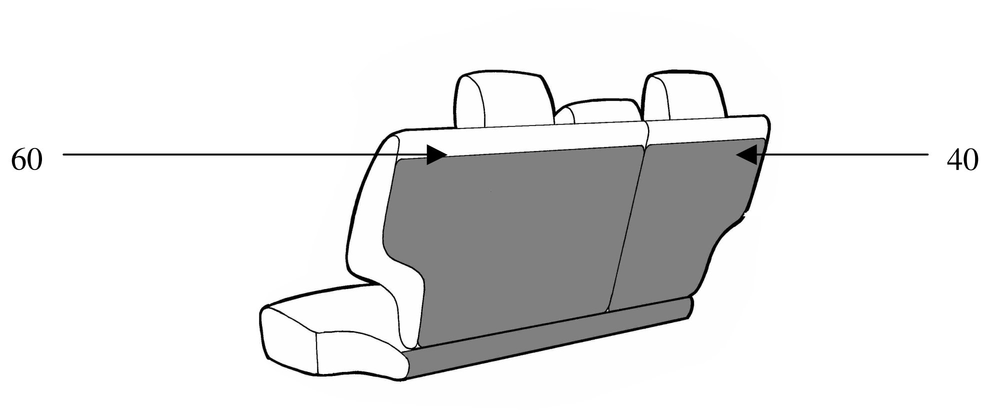


Figure 5-4: Rear Seat Partitioned (60:40)

The technical specification documents of the driver seat was analysed using the methodology described in the previous section. The results of the analysis is explained in subsequent sections

5.4.2 Document Analysis

The methodology starts by analysing the domain of the application, in this case, the car seat, which can be logically divided in to 5 subsystems, as shown in Table 5-2. The car seat is modular, as illustrated in Table 5-2.

Table 5-2: Subsystem Relationship Matrix for the Car Seat System

	Headrest	Backrest	Armrest	Cushion	Rail
Headrest	0	X			
Backrest	X	0	X	X	
Armrest		X	0		
Cushion		X		0	X
Rail				X	0

All five subsystems are interrelated. For example, if the width of the backrest is increased, the width of the cushion may need to be increased to conform. The position of the seat belt may also be affected. The subsystems form the high-level design parameter and are logically required to fulfil the high-level requirements, Table 5-3. Table 5-3 is suitable for external impact analysis (explained in chapter 6).

Table 5-3: High-Level Requirements and Design Parameters.

Requirements	Design Parameters
The seat must support the occupants head	Headrest
The seat must support the occupants back	Backrest
The seat must support the occupants arm	Armrest
The seat must support the occupants lower body	Cushion
The seat must be firmly secured in the vehicle	Rail

5.4.3 Identify Relevant Documents

Figure 5-5 depicts a set of relevant document in the manufacturing process of a car seat. These documents are related to the function of the product/system. For example, specification tenders are created in collaboration between OEM and their suppliers.

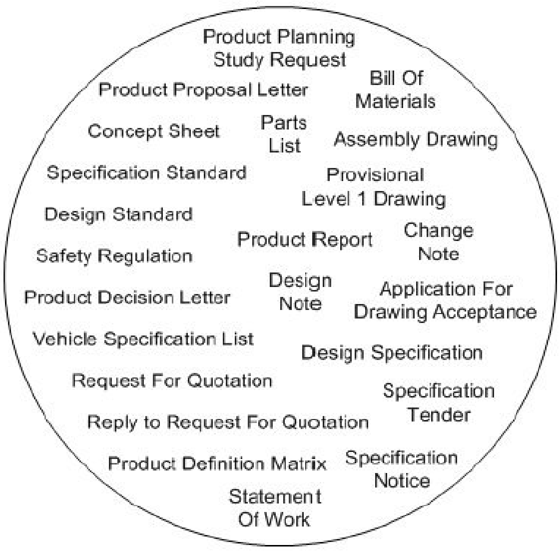


Figure 5-5: Documentation Sources – Seat System (Kerr *et al.*, 2004c).

Data Collection

Questionnaire and interviews were chosen as a preferred data collection technique due to time constraints and the limited knowledge of the author in the mechanical design industry. A request was made to the industrial collaborators for design engineers, cost estimators, purchasing staff (procurement staff), project managers and product specialists. The author made the request as a result of initial literature survey. After an initial visit to the industrial collaborators and an initial literature survey, questions relating to requirements management and cost estimation process was developed. The questionnaire was later modified to be more specific to cost estimation of requirement changes.

The documents in Figure 5-5 were identified in a series of one-to-one interview sessions with a major OEM and a Tier 1 Supplier. Data was collected using open-ended questions, in the form of semi-structured interviews. The interviews were recorded and transcribed later. Twelve interviews were conducted (seven with the OEM and five with the supplier). The interviews were two hours each. All interviewees were asked the same questions, though some questions were more relevant to some interviewees than others. For example, cost related question were typically more relevant to cost estimator and purchasers. While product interaction related question were more relevant to designers. There roles, positions and experience ranged from 2 years to 10 years. Some of the interviewees had switched role during their years of employment.

The author introduced the research to the interviewees using the research flyer to explain the benefits of the research first to the OEM-supplier relationship and second as a case study for the author. The interviews were recorded. Some notes were also taken, the recorded interviews were transcribed. After initial literature survey an appropriate research approach was adopted. The chosen research approach fit the research environment. The template approach was selected (Robson, 2002). The Delphi approach was also considered for its iterative questionnaire technique (Hamilton and Breslawski, 1996).

Figure 5-5 can be categorised under six headings: conceptual, design, parts, specification, quotation and homologation.

1 Conceptual

Conceptual documents are those documents that detail the rational behind the motivation to build a particular vehicle. Product Proposal Letter is issued to evaluate the Product Enhancement features requested by region in the Product Planning Study Request. For example, "Introduce Passenger Airbag Cut-off Switch (100%)".

Examples of conceptual documents:

1. Concept Sheet
2. Product Decision Letter – PDL (FR)
3. Product Proposal Letter – PPL (FR)

4. Product Planning Study Request

2 Design

Design documents are those documents that contain part drawings and design issues. For example, the design notes contains full details of design work to be carried out on vehicle model Examples of design documents:

1. Design Standard
2. Assembly Drawing
3. Product Definition Matrix
4. Design Note
5. Provisional Level 1 Drawing
6. Application for Drawing Acceptance
7. Statement of Work
8. Change Note

3 Parts

These documents contain a list of part that makeup the vehicle, including the amount of parts required.

Examples of parts documents:

1. Parts List
2. Product Report
3. Bill of Materials

4 Specification

Specifications documents usually contain detail geometry of the parts of a vehicle and can sometimes be accompanied by CAD drawings.

Examples of specification documents:

1. Vehicle Specification List (DP)
2. Design Specification
3. Specification Notice
4. Specification Tender
5. Specification Standard

5 Quotation

Quotation documents are specific to a design specification and are the official channel for requesting quotes on parts.

Examples of quotation documents:

1. Request For Quotation
2. Reply to Request For Quotation

6 Homologation

Vehicle homologation is the procedure for a vehicle to get part and type approval i.e. conforming to EU regulations in order to be sold in the EU states. Automotive organizations have homologation departments whose main job is to verify that a proposed vehicle conforms to the legal requirements of the EU.

Examples of homologation documents:

1. Safety Regulation

Identify Relevant Text

The next step involves scanning through the text of the relevant documents. When analysing the information in these document four questions are asked:

1. What must the system do – design requirements
2. How must the system achieve (1) – design parameter
3. What are the bounds on (1) – design requirements constraint
4. What are the bounds on (2) – design parameter constraint

The identification of requirements, design parameters, and constraints is iterative. Two levels of information are identified, high-level and low-level (leaf-level) design requirements and design parameters. The high-level design requirements and design parameters are for the subsystems, which can be used to assess change impact on external influence. While the leaf-level design requirements and design parameters can be use to conduct internal impact assessment.

Two documents from Figure 5-5 are used. Request for quotation (RFQ) and specification tender (ST) was used for the extraction methodology, due to access and availability of case study RFQ and ST are used for the extraction process. Sample RFQ and ST are shown in Appendix C.

Request for quotation and specification tenders contain within them requirements (R) and design parameters (DP) of a product. Requirements in the context of this research are 'what the product must do' and not customer requirements. Requirements and functional requirements are used interchangeably. These types of requirements are described as requirements (R). Rs were extracted with the aid of expert(s). An expert in this context is described as an employee of the tier one organisation who has an in-depth knowledge of the product. A list of requirements is generated; the requirements are classified into relevant types of design requirements.

Types of design requirements that can be identified:

Safety
Performance
Legislation
Comfort
Convenience

The type of requirement applicable to a module will depend on the type of module under consideration. Seat system will require all five requirements mentioned above, while other systems such as power-train does not necessarily have to be comfortable.

Product requirement types are identified, for example, the car seat has performance requirements, safety requirements, legislative requirements, comfort requirements, etc. An exhaustive list of all requirements including requirements that can change and non-changeable requirements are produced. Some of the requirement identified cannot be changed due to automotive product manufacturing legislation, for example, "the seat fabric must not be toxic". Non-changeable requirements are filtered from the initial list of identified requirements.

Constraints establish the bounds on the acceptable design solutions (Cochran *et al.*, 2000, Houshmand and Jamshidnezhad, 2002). Some of the remaining requirements will have constraints governing the range, for example "The occupant must be able to adjust the temperature of the seat" may have a constraint of 18 to 31 degrees centigrade. This means the temperature of the seat can only be adjusted to at least 18 degrees centigrade and at most 31 degrees centigrade.

Request for Quotation

The request for quotations (RFQ) contains features table and principal functions tables, from these two tables design requirement (design intent) can be derived. For example, in the feature table there is a section for “Adjuster”, as shown in Table 5-4. This is further divided into 4 sections, “Slide”, “Lifter”, “Recliner” and “Lumbar Support”. The Adjuster is an expectation from the seat, i.e. what the seat should do. Therefore, Adjuster is a requirement i.e. “the seat must be adjustable”. While Slide, Lifter, Recliner and Lumbar Support are the fulfilment of the requirements, i.e. how the requirements are satisfied. Travel and pitch are constraints on how the seat behaves, i.e. design parameter constraints.

Feature

Table 5-4: Feature List (RFQ)

<table>
<tr><td rowspan="4">Adjuster</td><td>Slide</td><td>Travel: More than 240mm/Pitch: Less than 12mm</td></tr>
<tr><td>Lifter</td><td>Travel: More than 50mm</td></tr>
<tr><td>Recliner</td><td>Pitch: Less than 2”</td></tr>
<tr><td colspan="2">Lumbar Support</td></tr>
</table>

The requirement “the seat must be adjustable” does not mean much by itself. This is a compound statement and it is not clear what is adjustable (the height or the support). The requirement is broken down further, i.e. what each of the design parameters (“Slide”, “Lifter”, “Recliner” and “Lumbar Support”) fulfil:

- (“Slide”) The seat must support lower body at suitable angle
- (“Lifter”) The seat height must be adjustable
- (“Recliner”) The seat's upper body support angle must be adjustable
- (“Lumbar Support”) The seat must provide additional support for the driver

Table 5-5: Sample Requirements and Design Parameters

Requirement	Design parameter	Constraints
The seat must support lower body at suitable angle	Slider	Travel: More than 240mm/Pitch: Less than 12mm
The seat height must be adjustable	Lifter	Travel: More than 50mm
The seat's upper body support angle must be adjustable	Recliner	Pitch: Less than 2"
The seat must provide additional support for the driver	Lumbar	

Each of the requirements above is satisfied by each of the design parameters identified earlier as shown in Table 5-5. To reduce bias the requirements and design parameters were validated by a seat designer.

Principal Function

The Principal Function table establishes a logical relationship between the requirements (Adjuster - the seat must be adjustable) and the design parameters (Slide, Lifter, Recliner and Lumbar Support).

Table 5-6: Principal Function of a Seat (RFQ)

Primary	Secondary	Tertiary	Seat function and structure
Driving	To ensure proper driving posture	To hold the occupant body	To hold the lower body
			To hold the upper body
			To hold the arm
			To hold the head
		Operability during driving	To adjust height
			To adjust seat-back cushion angle
			To adjust the foam of the seat back
			To adjust the seat back angle

The design parameters are then related to their requirements. The identified requirements, design parameters and constraints are catalogued in a repository. The Principal Function table contains descriptions of what the seat should do, Table 5-6. For example, one of the principal functions according to the author of the specs is driving; others are convenience, comfort, etc. A secondary function is "To ensure proper driving posture" A tertiary function is "To hold the occupant body"; each of the function level corresponds to a requirement hierarchy. Finally, the entries under the "Seat function and structures" are leaf-level requirements.

The two document segments (Table 5-4 and Table 5-6) are related. Since the ability of the seat to hold the upper body in a proper driving posture "a principal function" mutually depends on how well the specification of the "feature lists" are defined.

Relationship between Table 5-4 and Table 5-5 are enumerated below:

- Slider in Table 5-5 has constraints "Travel: More than 240mm/Pitch: Less than 12mm" in Table 5-4
- Slider in Table 5-4 is a fulfilment of the requirements "The seat must support lower body at suitable angle" in Table 5-5

Two types of constraint are identified: constraints on requirements and constraints on design parameter as depicted in Figure 5-1. For example, "the seat must be able to hold a weight of 100kg" indicates that 100kg is a requirements constraint. While "the length of the cushion frame is 200mm" indicates that 200mm is a design parameter constraint.

Table 5-7, the Seat Basic Dimension table contains constraints on design parameters. Table 5-7 also defines the bounds on acceptable solutions (design parameters). This table associate design parameters to their constraints. Constraints define the bounds on the design solutions that are acceptable to the customers. Constraints limit the set of acceptable design solutions (design parameters) and influence the definition and scope of the requirements at lower levels of the design hierarchy.

Table 5-7: Seat Basic Dimension Table (RFQ)

			DOM			
			RHD			
			W32G [GN]	J32B C-MPV	W32C [NR]	W32E [NZ]
Seat Type A			Separate	Separate	Separate	Separate
Core Dimension	Neutral Torso Angle	-	21	21	21	21
	Cush Width	-	530	515	520	530
	Cush Length	H.P.~Cush Fr Edgegle	365	365	367	365
	Back Width	-	530	515	500	530
	Back Height	H.P.~Back To Edgegle	580	580	570	580

Specification Tender - Document

Specification tender is another design document used in the car seat development as illustrated in Figure 5-5. Similar to the RFQ the specification tender also contains requirements, design parameters, and their constraints. For example, Table 5-8 illustrates seat features and functions, the table also contain allowable bounds (constraints) on the feature and functions.

The anti submarine stops the occupant from sliding forward under the seat restraint in the event of a sudden stop. Anti submarine feature is part of how the seat supports the lower body of the occupant, this is achieved through the slide mechanism in the seat cushion. “Anti submarine” is a design parameter that specifies how a requirement is achieved. “Support the lower body” is a requirement that is satisfied by the “Anti submarine”.

The next row gives an example of requirements constraint, the requirements is “the system must protect the occupant in the event of sudden side impact”, as shown in Table 5-8 the design parameter is “Side Airbag”. 2445.3N may be confused as a design parameter constraint, but this value relates to the amount of force required to deploy the protection mechanism (requirements) and not the dimension or type of airbag. Hence, 2445.3N is a requirements constraint.

Table 5-8: Extract from the Specification Tender

Anti submarine RR seat	RR sliding seat must have anti submarine feature
Side Airbag deployment performance	Side Airbag Minimum deployment force is 2445.3N
Comfort	FF & RR Headrest – Must avoid strange feeling because of the big difference of the foam hardness between headrest and seat back
Rcl operate structure	Lever type or Dial type, either type is OK.

Table 5-9: Plastic Parts (ST)

Item		**Part**
FR	1	HLDER ASSY-HRST, LOCK
	2	HLDER ASSY-HRST, FREE
	5	KNOB LIFTER LEVER RH/LH
	7	KNOB-RCLNG DVC LEVER, RH/LH

Table 5-9 contains design parameters, since it specifies how exact functions are achieved. Design parameters are sometimes BOM (bill of material) items. Items 1 and 2 (HLDER ASSY-HRST, LOCK and HLDER ASSY-HRST, FREE) both relate to the headrest (design parameter), which is how "the system supports the occupants head" (requirements) in Table 5-6.

5.4.4 Create logical Hierarchy of Requirements and Design Parameters

The extracted information is catalogued in a repository Table 5-10. Table 5-10 contains subsystem of the seat, the requirements related to the subsystems and the design parameter related to the requirements. Some requirements and design parameters may also have constraints; all of this information is arranged in a structured manner. The results from the exercise above is used for the determination of impact propagation path and cost assessment of requirement change.

5.4.5 Create Matrixes and Establish Relationships

Three types of matrixes were created: requirements (R/R), requirement/design parameter (R/DP) and design parameter (DP/DP). Table 5-10 was used to populate the matrixes; this was done with a design engineer. The validation of the matrixes is explained in section 5.6.

Requirements Matrix

Table 5-11 is a relational matrix that illustrates the relationship between requirements of the seating system. The matrix indicates the extent of impact by S-Strong, M-Medium and W-Weak, as illustrated in Table 5-1. The propagation path of changes is determined by extracting all strongly impacted requirements. Propagation path generation is governed by the stop criteria in section 5.3. Therefore, the propagation path consists of the affected requirements.

Requirements versus Design Parameters Matrix

The affected requirements identified from the requirements matrix are used to identify associated design parameters, from Table 5-12. The result of this exercise is a list of affected design parameters. This list is a worst case scenario, which will require an engineer's assessment for most relevant design parameters to be considered for cost estimation.

Design Parameter Matrix

Table 5-13 illustrates a third type of relational matrix that is used for constraints changing on design parameter. However, the use of this matrix does not require the stop criteria, as only one level of propagation is sufficient. The list of affected design parameter presents a worst case scenario which will also require an engineer to select most relevant design parameters for cost estimation.

Table 5-10: Repository for Requirements, Requirement Constraints, Design Parameters and Design Parameter Constraints

High-level Requirements		Low-level Requirements						
	DP (Subsystem)	Requirements	R-Constraints	External Impacts		DPs	DP-Contraints	External Impacts
The seat must support occupants head	Headrest	The seat must be able to support the occupant's head		Body-in-white, Interior trim	1	Front-Holder assembly -headrest, lock	Head room dimension from hip point	
					2	Front-Holder assembly -headrest, free	Head room dimension from torso angle	
					3	Headrest frame	Active headrest pitch angle	Body-in-white
					4	Headrest fabric	Active headrest travel distance	Interior trim
					5	Headrest foam	Overhead clearance in vehicle	
The seat must support occupants back	Backrest	The seat must be able to support the occupant's upper body		Dashboard, Interior trim	6	Front seat backrest frame right/left	Seat torso angle from hip point (neutral torso angle)	Dashboard
		The seat's upper body support angle must be adjustable		Dashboard, Interior trim	7	Front seat backrest right/left fabric	Clearance distance to steering wheel torso neutral position	Interior trim
		The seat must provide additional support for the driver		Dashboard, Interior trim	8	Front seat backrest right/left foam		
					9	Lumbar support unit	Lumbar support travel	
							Lumbar angle of rotation	
The seat must support occupants arm	Armrest	The seat must be able to support the occupant's arm			10	Front armrest frame right/left	Armrest position from hip point	
					11	Front armrest right/left fabric		Interior trim
					12	Front armrest right/left foam		
The seat must support occupants lower body	Cushion	The seat must be able to support the occupant's lower body		Dashboard, Interior trim	13	Front seat cushion frame right/left	Hip point	Dashboard
		The seat's lower body support angle must be adjustable		Dashboard, Interior trim	14	Front seat cushion right/left fabric	Heel point	Interior trim
					15	Front seat cushion right/left foam	Seat cushion angle from hip point	
					16	Anti-submarine feature	Clearance distance to pedals from heel point	
					17	Front-Finish assembly cushion, front seat right/left inner		
					18	Front-Finish assembly cushion, front seat right/left outer		
The seat must be firmly secured in the vehicle	Rail	The seat height must be adjustable	±25 deg from vertical	Body-in-white, Interior trim	19	Rail slide	Fixing point coordinates of front seat-inner front	Body-in-white
		The seat must be firmly secured in the vehicle	x-1024.5, y-161.6, z-71.3	Body-in-white, Interior trim	20	Slide floor bracket	Fixing point coordinates of front seat-inner rear	Body-in-white
							Fixing point coordinates of front seat-outer front	
							Fixing point coordinates of front seat-outer rear	
					21	Front-Knob -lifter level right/left	Travel: more than 50mm	Interior trim
							Travel: More than 240mm	
							Pitch: Less than 12mm	
	Seat belt	There must be mechanism to remind the occupant to use their seat belt	Front seat only	Interior trim	22	Seat belt reminder mechanism		Electronics
					23	Seat belt bracket		
					24	Seat belt fabric		Interior trim
	Power seat				25	Power seat motor for recliner		Electronics
					26	Power seat motor for front lifter		Electronics
					27	Power seat motor for slide		Electronics
		The seat must have temperature control	18 C-31 C	Electronics	28	Seat heating mechanism	18 C-31 C	Electronics
		The seat quality when touched must be good		Interior trim	29	Softness of seat fabric	type of fabric	Interior trim
		The seat quality must not be rigid		Interior trim	30	Softness of seat foam	type of foam	Interior trim
		The decoration, covering, concealment and interception of light must not be unpleasant		Interior trim				Interior trim
					31	Front-Cover-reclining DVC, front seat right/left inner	Seat back reclining angle	
					32	Front-Knob -reclining DVC lever, right/left		
					33	Front-Cover-seat slide rear inner right		Interior trim
					34	Front-Cover-seat slide rear inner left		Interior trim
					35	Front-Cover-seat slide rear outer right		Interior trim
					36	Front-Cover-seat slide rear outer left		Interior trim
					37	Front-Cover-seat slide front inner right		Interior trim
					38	Front-Cover-seat slide front inner left		Interior trim
					39	Front-Cover-seat slide front outer right		Interior trim
					40	Front-Cover-seat slide front outer left		Interior trim

Table 5-11: Requirements Relationship Matrix for Seating System

		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14
		The seat must be able to support the occupant's lower body	The seat must be able to support the occupant's upper body	The seat must be able to support the occupant's arm	The seat must be able to support the occupant's head	The occupant must be able to adjust the height the seat can travel	The occupant must be able to adjust the seat-cushion angle	The occupant must be able to adjust the seat-back angle	The occupant must be able to adjust the seat-back foam	The occupant must be able to adjust the temperature of the seat	The decoration, covering, concealment and interception of light must not be unpleasant	The seat quality when touched must be good	The seat quality must not be rigid	The seat must be firmly secured in the vehicle	There must be mechanism to remind the occupant to use their seat belt
R1	The seat must be able to support the occupant's lower body	0	S			M	W	W	W	M	W	M	M	S	
R2	The seat must be able to support the occupant's upper body	S	0	S	S			S	S	W	W	M	M		M
R3	The seat must be able to support the occupant's arm		S	0								M	M		
R4	The seat must be able to support the occupant's head		S		0	S						M	M		
R5	The seat height must be adjustable	M			S	0									
R6	The seat's lower body support angle must be adjustable	W					0								
R7	The seat's upper body support angle must be adjustable	W	S					0							
R8	The seat must provide additional support for the driver	W	S						0						
R9	The occupant must be able to adjust the temperature of the seat	M	W							0					
R10	The decoration, covering, concealment and interception of light must not be unpleasant	W	S								0				
R11	The seat quality when touched must be good	M	M	M	M							0			
R12	The seat quality must not be rigid	M	M	M	M								0		
R13	The seat must be firmly secured in the vehicle	S												0	
R14	There must be mechanism to remind the occupant to use their seat belt		M												0

Legend	
S	Strong
M	Medium
W	Weak

Table 5-12: Requirements and Design Parameter Matrix

		DP1 Seat heating mechanism	DP2 Seat belt reminder mechanism	DP3 Seat belt bracket	DP4 Anti-submarine feature	DP5 Seat belt fabric	DP6 Power seat motor for recliner	DP7 Power seat motor for front lifter	DP8 Slide floor bracket	DP9 Front-Holder assembly -headrest, lock	DP10 Front-Holder assembly -headrest, free	DP11 Front-Finish assembly cushion, front seat right/left inner	DP12 Front-Finish assembly cushion, front seat right/left outer	DP13 Front-Knob -lifter level right/left	DP14 Front-Cover-reclining DVC, front seat right/left inner	DP15 Front-Knob -reclining DVC lever, right/left	DP16 Front-Cover-seat slide rear inner right	DP17 Front-Cover-seat slide rear inner left	DP18 Front-Cover-seat slide rear outer right
R1	The seat must be able to support the occupant's lower body				x			x	x			x	x	x			x	x	x
R2	The seat must be able to support the occupant's upper body			x		x	x								x	x			
R3	The seat must be able to support the occupant's arm																		
R4	The seat must be able to support the occupant's head									x	x								
R5	The occupant must be able to adjust the height the seat can travel													x					
R6	The occupant must be able to adjust the seat–cushion angle																		
R7	The occupant must be able to adjust the seat-back angle														x	x			
R8	The occupant must be able to adjust the seat-back foam																		
R9	The occupant must be able to adjust the temperature of the seat	x																	
R10	The decoration, covering, concealment and interception of light must not be unpleasant																		
R11	The seat quality when touched must be good																		
R12	The seat quality must not be rigid																		
R13	The seat must be firmly secured in the vehicle																		
R14	There must be mechanism to remind the occupant to use their seat belt		x																

		DP19 Front-Cover-seat slide rear outer left	DP20 Front-Cover-seat slide front inner right	DP21 Front-Cover-seat slide front inner left	DP22 Front-Cover-seat slide front outer right	DP23 Front-Cover-seat slide front outer left	DP24 Power seat motor for slide	DP25 Headrest frame	DP26 Front seat backrest frame right/left	DP27 Front seat cushion frame right/left	DP28 Front armrest frame right/left	DP29 Slide seat rail	DP30 Headrest fabric	DP31 Front seat backrest right/left fabric	DP32 Front seat cushion right/left fabric	DP33 Front armrest right/left fabric	DP34 Headrest foam	DP35 Front seat backrest right/left foam	DP36 Front seat cushion right/left foam	DP37 Front armrest right/left foam
R1	The seat must be able to support the occupant's lower body	x	x	x	x	x	x			x		x			x				x	
R2	The seat must be able to support the occupant's upper body								x					x				x		
R3	The seat must be able to support the occupant's arm										x					x				x
R4	The seat must be able to support the occupant's head							x					x				x			
R5	The occupant must be able to adjust the height the seat can travel																			
R6	The occupant must be able to adjust the seat–cushion angle																			
R7	The occupant must be able to adjust the seat-back angle																			
R8	The occupant must be able to adjust the seat-back foam								x					x				x		
R9	The occupant must be able to adjust the temperature of the seat																			
R10	The decoration, covering, concealment and interception of light must not be unpleasant												x	x	x	x				
R11	The seat quality when touched must be good																			
R12	The seat quality must not be rigid																			
R13	The seat must be firmly secured in the vehicle											x								
R14	There must be mechanism to remind the occupant to use their seat belt																			

Table 5-13: Design Parameter Relationship Matrix

		DP1 Seat heating mechanism	DP2 Seat belt reminder mechanism	DP3 Seat belt bracket	DP4 Anti-submarine feature	DP5 Seat belt fabric	DP6 Power seat motor for recliner	DP7 Power seat motor for front lifter	DP8 Slide floor bracket	DP9 Front-Holder assembly -headrest, lock	DP10 Front-Holder assembly -headrest, free	DP11 Front-Finish assembly cushion, front seat right/left inner	DP12 Front-Finish assembly cushion, front seat right/left outer	DP13 Front-Knob -lifter level right/left	DP14 Front-Cover-reclining DVC, front seat right/left inner	DP15 Front-Knob -reclining DVC lever, right/left	DP16 Front-Cover-seat slide rear inner right	DP17 Front-Cover-seat slide rear inner left	DP18 Front-Cover-seat slide rear outer right	DP19 Front-Cover-seat slide rear outer left	DP20 Front-Cover-seat slide front inner right	DP21 Front-Cover-seat slide front inner left	DP22 Front-Cover-seat slide front outer right	DP23 Front-Cover-seat slide front outer left	DP24 Power seat motor for slide	DP25 Headrest frame	DP26 Front seat backrest frame right/left	DP27 Front seat cushion frame right/left	DP28 Front armrest frame right/left	DP29 Slide seat rail	DP30 Headrest fabric	DP31 Front seat backrest right/left fabric	DP32 Front seat cushion right/left fabric	DP33 Front armrest right/left fabric	DP34 Headrest foam	DP35 Front seat backrest right/left foam	DP36 Front seat cushion right/left foam	DP37 Front armrest right/left foam
DP1	Seat heating mechanism	0	X	X																							X	X				X	X			X	X	
DP2	Seat belt reminder mechanism	X	0	X		X																																
DP3	Seat belt bracket	X	X	0																																		
DP4	Anti-submarine feature				0																							X									X	
DP5	Seat belt fabric		X			0																									X	X	X	X				
DP6	Power seat motor for recliner						0																															
DP7	Power seat motor for front lifter							0																														
DP8	Slide floor bracket								0																					X								
DP9	Front-Holder assembly -headrest, lock									0	X																											
DP10	Front-Holder assembly -headrest, free									X	0																											
DP11	Front-Finish assembly cushion, front seat right/left inner											0																										
DP12	Front-Finish assembly cushion, front seat right/left outer												0																									
DP13	Front-Knob -lifter level right/left													0																								
DP14	Front-Cover-reclining DVC, front seat right/left inner														0	X																						
DP15	Front-Knob -reclining DVC lever, right/left														X	0																						
DP16	Front-Cover-seat slide rear inner right																0	X	X	X	X	X	X	X														
DP17	Front-Cover-seat slide rear inner left																	0	X	X	X	X	X	X														
DP18	Front-Cover-seat slide rear outer right																	X	0	X	X	X	X	X														
DP19	Front-Cover-seat slide rear outer left																	X	X	0	X	X	X	X														
DP20	Front-Cover-seat slide front inner right																	X	X	X	0		X	X														
DP21	Front-Cover-seat slide front inner left																	X	X	X	X	0	X	X														
DP22	Front-Cover-seat slide front outer right																	X	X	X	X	X	0	X														
DP23	Front-Cover-seat slide front outer left																	X	X	X	X	X	X	0														
DP24	Power seat motor for slide																								0													
DP25	Headrest frame																									0					X				X			
DP26	Front seat backrest frame right/left	X																									0					X				X		
DP27	Front seat cushion frame right/left	X			X																							0					X				X	
DP28	Front armrest frame right/left																												0					X				X
DP29	Slide seat rail								X																					0								
DP30	Headrest fabric					X																				X					0	X	X	X	X			
DP31	Front seat backrest right/left fabric	X				X																					X				X	0	X	X		X		
DP32	Front seat cushion right/left fabric	X				X																						X			X	X	0	X			X	
DP33	Front armrest right/left fabric					X																							X		X	X	X	0				X
DP34	Headrest foam																									X					X				0			
DP35	Front seat backrest right/left foam	X																									X					X				0		
DP36	Front seat cushion right/left foam	X			X																							X					X				0	
DP37	Front armrest right/left foam																												X					X				0

5.4.6 Validation of REXTRAM

The repository generated by REXTRAM Table 5-10 and the matrixes created from the repository Table 5-11, Table 5-12 and Table 5-13 were validated by six experts. The validation workshop was held at a Tier 1 Supplier office. The six experts were the OEM, Tier 1 Supplier and the e-RM project, as illustrated in Table 5-14. The validation session lasted a whole day. One half of the day was spent on the presentation of the methodology, while the second half of the day was spent on the population of the matrixes (including ranking or requirements relationship).

The steps of the methodology were presented to the participants. After the presentation the participants populated the 3 matrixes (Table 5-11, Table 5-12 and Table 5-13) with the extracted data in Table 5-10. This was done by individually going through each entry in each matrix. The feedbacks were documented and modifications were made to the methodology.

Table 5-14: List of REXTRAM Validation Participants

Job Title	**Organisation**	**Years of Experience**
Knowledge Management	OEM	10
Knowledge Management and Audit	OEM	5
Design Manager	Tier 1 Supplier	7
Project Cost Manager	Tier 1 Supplier	5
Purchasing Manager	Tier 1 Supplier	5
e-RM Project Manager	Cranfield University	0

The matrix representation captured the interrelationships between product requirement and requirement solutions. The designers verified that the relationships and extent of relationships between requirements was a true reflection of the seating systems. The ranking of extent of impact was also validated. The design parameters matrix, including the relationships between design parameters was also validated.

Two modifications were made to the initial extraction methodology.

1. The categorisation of document sources illustrated in section 5.3.2 was one of such changes.

2. The creation of stop criteria for ripple effect propagation path, illustrated in chapter 6. The participants mentioned that the first two matrixes were easy to populate, but the third was quite cumbersome.

The creation of the matrixes was challenging since the researcher has limited knowledge about the automotive industry. However, the novelty of REXTRAM applies to any industry that is inundated with design documents.

5.5 Key Observations

- First tier automotive suppliers are responsible for the product development of 'black box' and 'grey box' modular systems.
- The specification of such systems is becoming increasingly important as the OEM's requirements need to be completely and clearly represented in the form of engineering definitions since the specification is the principal means of communication.
- However, in practice most specifications are often unstructured and use various vocabularies.
- More importantly, requirements are represented in the form of natural language and this can potentially result in semantic mismatches in the form of ambiguities, inconsistencies and even omissions. This of course increases the communication effort.
- Hence, the need for a formal and structured design requirements and design parameters extraction methodology.
- The idea of developing a methodology that explicitly defines relationships among the components of a system presents several benefits, such as enabling management to identify inconsistencies and inefficiencies in product definition.
- Finally, it was observed that REXTRAM is easy to understand, as experts and novice design engineers were able to understand the concepts portrayed by the methodology

5.6 Summary

This chapter has presented the development and validation of a relevant data extraction methodology (REXTRAM). The methodology is further validated with another case study, the cooling system illustrated in chapter 7.

This research presents a novel methodology to extract evolving design requirements and related design parameters from documents in both the OEM and suppliers organisations. This way it is possible to identify different levels of requirements, design parameters and the relationships between them.

REXTRAM is a generic methodology developed using semi-structured interviews, flowchart and matrixes. This methodology is applicable to mechanical design components within the automotive industry. The research has used a case study based approach to develop the methodology. The methodology and the case study were validated using expert judgement. The objective is to present a methodology to extract systems level design requirements and design parameters for Cost Impact Analysis of requirement changes within the automotive industry (explained in chapter 6).

The next section starts by describing cost impact analysis methodology (CIAM). The methodology qualitatively assesses the incurred cost when a requirement change is proposed. CIAM also serves as a validation of the extraction methodology.

6 COST IMPACT ANALYSIS METHODOLOGY

6.1 Introduction

In Chapter 2, several requirement management tools and cost estimation tools were reviewed for their relevance to the research. The main conclusions are as follows: 1) that cost estimation of requirement changes are carried out by experience based on the assumption that all possible effect of requirement change propagation can be determined by experience; 2) that the available requirement management and cost estimation tools do not adequately cater for the cost estimation of requirement changes. This made it difficult to either reuse or understand the rationale behind requirement change cost estimation.

In Chapter 5, a relevant data extraction methodology REXTRAM was developed to justify and validate the data (requirements, design parameters and their constraints) used for the cost estimation of requirement changes and change impact analysis. Several data collection and data analysis techniques were used such as questionnaires, semi-structured interviews and flowchart. This chapter focuses on the development of Cost Impact Analysis Methodology for requirement changes during the design stage of automotive mechanical products. Similar to REXTRAM, this is achieved by using template research approach, as explained in chapter 3.

Chapter Aim:

To develop a generic cost impact analysis methodology for cost estimation of design requirement changes for complex mechanical design component within the automotive industry.

This chapter is structured as follows: section 6.2 presents the motivation for creating cost impact analysis methodology (CIAM). Section 6.3 discusses the development of CIAM and types of changes addressed by CIAM. Section 6.4 describes the application of the methodology on the car seating system. Section 6.5 provides the validation of results obtained from the application of CIAM on the seating system.

Section 6.6 presents the key observations. In section 6.7, the author summarises the chapter and before moving onto chapter 7, where REXTRAM and CIAM are further validated with another case study, the cooling system.

6.2 Motivation

Requirement changes can have internal impact/external impact on the cost and design of a product. Internal cost impact analysis focuses on the relationships between the requirements and design parameters within a system. For example, how a change to one part of a seat ripples to other parts of that seat. External impact analysis will focus on the interrelationships between systems of a product. For example, how a change to one system (seat) may ripple to other systems (body-in-white, interior-trim).

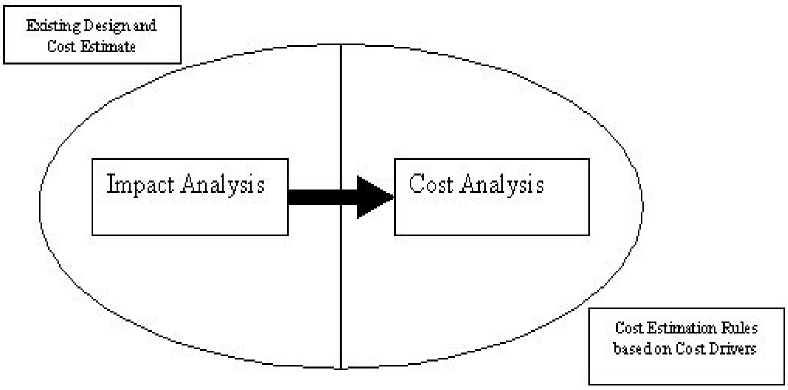


Figure 6-1: Cost Impact Analysis Solution Architecture

Cost impact analysis is further addressed in two phases; impact analysis and cost analysis, as depicted in Figure 6-1. Impact analysis deals with the ripple propagation effect of changing one component on other related components. Cost analysis deals with the cost estimation of the proposed change. The cost here is addressed as delta cost i.e. the incurred cost as a result of making a requirement change. Cost impact analysis methodology is developed using the car seating system as a case study.

6.2.1 Impact Analysis

After a further review of related research work (Clarkson *et al.*, 2001, Cohen and Fulton, 1998, Cohen *et al.*, 2000, Malmqvist, 2002, Becker and Wang, 2003, Guenov and Barker, 2004), the author identified that the product specification document also contains product structures. The specification document was used to identify product requirements (functional requirements). The product structure also contained the design solutions to the product requirements (design parameters). On closer examination it was discovered that some requirements had more than one design parameter and vice versa.

The relationship between the requirements and the design parameters can be represented using a matrix approach e.g. axiomatic design (AD) (Suh, 1995, Lee et al., 2001, Cochran and Vicente, 1996, Houshmand and Jamshidnezhad, 2002, Sudjianto and Otto, 2001, Suh, 2001, Cochran et al., 2000) and design structure matrix (DSM) (Yassine, 2002, Browning, 2001, Eppinger et al., 1994, Pimmler and Eppinger, 1994, McCord and Eppinger, 1993, Steward, 1991, Steward, 1981, Yassine and Braha, 2003). A decision was made not to incorporate AD or DSM, since AD assumes that the product was developed by following AD principles.

Expert judgement played a large part in the development of the methodology (Rush and Roy, 2001b, Finnie *et al.*, 2000). The designers will fill and create the matrixes and the cost driver's correspondingly.

Three types of matrixes are used for product data representation:

Requirements to requirements (R/R) matrix (nxn)

Requirements to design parameters (R/DP) matrix (nxm)

Design parameters to design parameters (DP/DP) matrix (mxm)

6.2.2 Cost Analysis

Cost estimation approach used the requirements, design parameters and cost drivers to determine the delta cost of a change at the worst case scenario. The cost drivers are those factors, within the specification document, that adversely affect the cost of the product if a change is made. The cost drivers can be tooling, materials, labour and machinery, design, bought-out-items, packaging, delivery, storage, etc.

Within the OEM-supplier relation used for this research it was observed that tooling cost is the main cost driver. Tooling was used to determine the extent to which a requirement affects another requirement. Similarly, tooling was used to determine the extent to which a design parameter affects another design parameter. The result of the relationships was presented as a matrix. The output of the matrix is a propagation path of affected requirements and design parameters.

Cost estimation requires existing data. The degree to which existing data is available will determine the cost estimation technique used. Analogy cost estimation was initially proposed. Analogy cost estimation will require existing cost data from similar and past projects. Cost data was not available due to the competitive nature of the automotive industry. Rule based approach was implemented for cost estimation instead. Rule based approach requires a series of what-if rules.

6.3 Development of Cost Impact Analysis Methodology (CIAM)

This section begins with an introduction on how the final methodology was conceived. The inputs needed for the methodology are extracted from the design specification documents (Chapter 5). A discussion of the different parts of the methodology is presented; impact analysis and cost analysis. The section concludes with a description of the cost estimation technique used to determine the delta cost of a requirement change.

Automotive product developments are modular (Kerr *et al.*, 2004c), each module constitutes a system. These systems are outsourced to Tier 1 Suppliers, who shares responsibility with the original equipment manufacturer (OEMs). A change will always have an origin, for example, a change in the seat system may have its origin as an increase in the size of the headrest. The change will be associated with a requirement and the increase in size will be translated to one or more design parameters (frame, foam, fabric).

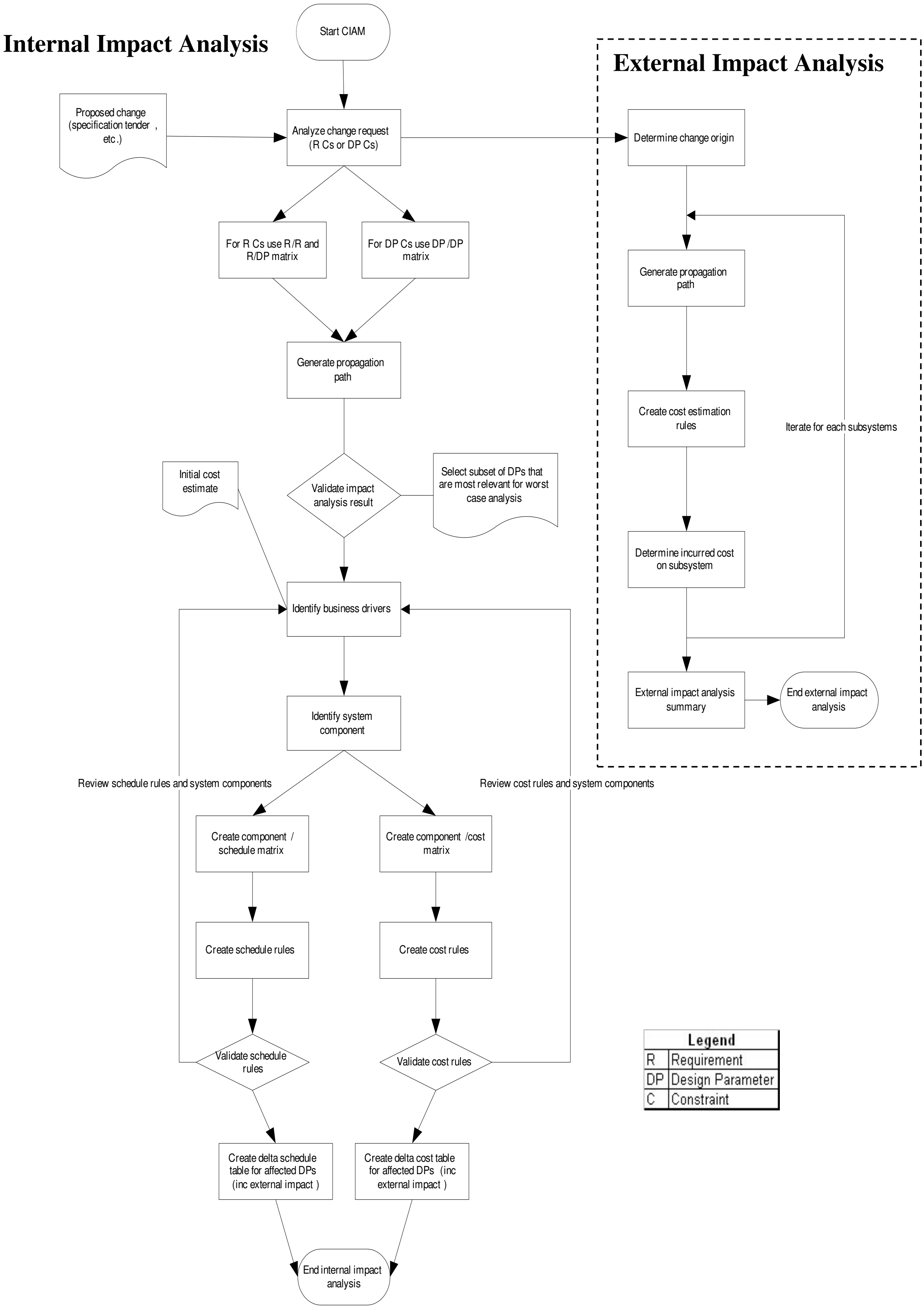


Figure 6-2: Cost Impact Analysis Methodology for Design Requirement Changes Management within the Automotive Industry (CIAM)

The observations from the AS-IS and literature surveys have led to the creation of 'Cost Impact Analysis Methodology for Requirement Changes within the Automotive Industry'. The flowchart in Figure 6-2 illustrates the steps required for the proposed methodology. As mentioned earlier, CIAM is a two-part methodology that determines internal incurred cost of a change and external incurred cost of a change. Both internal and external cost impact are viewed from two perspectives impact analysis and cost analysis (Figure 6-1). Table 5-10 (in chapter 5) is used to populate the three types of matrix requirements/requirements (R/R), requirements/design parameter (R/DP) and design parameter/design parameter (DP/DP) matrixes.

6.3.1 Internal Cost and Time Impact Analysis

CIAM starts with internal cost impact analysis. Internal cost impact analysis deals with the cost estimation of requirement changes within a system. For example in the car seating system, a change to the backrest of the seat may have an effect on the total height of the seat, i.e. the headrest; the seat cushion and the seat rail will be affected. Internal cost impact analysis looks at the cost and impact of carrying out the initial change, the effect of the initial change on the rest of the seat and the potential cost of changing other components of the seat.

Analyse requirement change (R Cs or DP Cs)

CIAM identifies two types of requirement changes:

1. Constraints changing on Rs (R/R and R/DP), and
2. Constraints changing on DPs (DP/DP)

For constraints changing on Rs, R/R and R/DP matrix are applied. The first step is to identify the affected Rs from the R/R matrix. The next step is to identify associated DPs from R/DP matrix. For constraints changing on DPs the DP/DP matrix is used to generate affected DPs. The resulting DPs form the foundation for cost assessment.

Constraints changing on requirements

When a requirement is changed there is the tendency for the change to ripple to other requirements. The result of using this matrix is a list of affected requirements. Each requirement is related to one or more associated design parameter. These results can be used to evaluate the cost of a proposed change.

Constraints changing on design parameters

A list of affected design parameters is generated by relating a design parameter to associated design parameters in the table. The result of applying this table is a list of affected design parameters. Similar to constraints changing on requirements, these results can then be used to evaluate the cost of a proposed change.

Generate propagation path

The propagation path generated is a worst case scenario. This list is a worst case scenario, which will require an engineer's assessment for most relevant design parameters to be considered for cost estimation. The methodology generates as many design parameters (DPs) as can be related to a particular requirement change. For example, a change to the seat will only affect the seat electronic when the seat is a power seat (i.e. seat that have electric controls). Initial list of DPs will include the DPs specific to the electronics the engineers will have to assess the most relevant DPs.

Validate impact analysis result

Select subset of DPs that are most relevant for the type of requirement change that will need to be validated. This will be conducted by a domain expert.

Identify business drivers

Business drivers are identified; these are the factors that have major effect on development cost (Roy *et al.*, 2001) and schedule. Two types of business drivers are considered cost drivers and time drivers. For example, tooling can be a business driver in scenarios where the cost of tooling determines to a large extent a major increase in cost of development. Other business drivers can be Raw Materials, Design, Labour, etc (Roy *et al.*, 2004a).

The formula below highlights the essential components of a cost impact assessment procedure using the business drivers:

$$\mathbf{CI = T + R + L + M + B + O + D} \qquad \textbf{equation 1}$$

Where

CI is the delta cost of a requirement change on piece cost

T is the cost of tooling required (foam, frame and fabric parts)

R is the cost of raw materials required

L is the cost of labour required

M is the cost of machinery required

B is the cost of bought-out item from external suppliers (usually plastic parts)

O is the cost of overhead (rates, rent, admin staff, electricity, rates, council tax, property tax etc).

D is the cost of design work done

The proposed methodology is based on product decomposition. For example, car seats have various parts and can be classified as small, medium or large. The collaborators mentioned that the seat parts are classified as illustrated in Table 6-1.

Table 6-1: Classification of the Seating System

Small	headrest, armrest, bolster
Medium	front backrest, front cushion, rear backrest 40%, rear backrest 50%, rear cushion 40%, rear cushion 50%,
Large	rear backrest bench, rear backrest 60%, rear cushion, rear cushion 60%

Table 6-2: Business Drivers and Product Components

	Foam	Frame	Fabric	Plastic
Tooling	X	X	X	
Raw Materials	X	X	X	
Labour	X	X	X	
Machinery	X	X	X	
Bought-out-items				X

Identify system component

The components of the product are related to the business drivers. For example the automotive seat is essentially made-up of three components, namely foam, frame and fabric. The industrial case study (collaborator) use only a subset of the identified business drivers; tooling, materials, labour, machinery, and bought-out-items.

Table 6-2 below illustrates the relationship between the business drivers and the product components.

A relational matrix for the business drivers and the components of the seating system was created. Table 6-2 is used for cost and time rules. Table 6-2 shows that tooling cost is incurred on moulding of the seat foam, the forming of seat frame and the sewing of the fabric. Raw material cost is incurred for the foam chemical, the metal sheet that is cut into the frame and the fabric material. Labour and machinery cost are incurred on the operation of the foam moulding machine. Labour and machinery cost are incurred on the operation of the forming machine used for the cutting and shaping of metal sheet to frames. Labour and machinery cost are also incurred on the operation of the sawing machine used to sew the seat fabric. Bought-out-items are only applicable for plastic parts. In total 13 rules are required as denoted by the number of Xs in Table 6-2

Create time driver /product component matrix

The business drivers and product component matrix (Table6-2) shows the relationship between the business drivers and the product components. This representation illustrates the number of time rules require.

Create time rules

The time drivers are then used to create a set of time rules (what-if and if-then-else) depending on the size of the affected parts. The time rules are developed in collaboration with the Design Engineers and Cost Estimator, by identifying the incurred (delta) time, required to implement a proposed requirement change. The part affected by a change request is grouped according to its size (small, medium and large). The time rules captured possible scenarios of different combinations of the time drivers.

Validate time and cost rules

The resulting rules will have to be validated by a cost estimator. The validation will include the input to trigger sections of the what-if rules.

Create cost driver/ product component matrix

Similar to the component/time matrix, the component/cost matrix shows the relationship between the cost drivers and the system components. This representation also illustrates the amount of cost rules required.

Create cost rules

Similar to the time drivers, the cost drivers are then used to create a set of cost rules (what-if and if-then-else) depending on the size of the affected parts. The parts affected by a change request are also grouped according to their size (small, medium and large) as in the time rules. These cost rules will also capture possible scenarios of different combinations of the cost drivers. The delta cost is the incurred cost as a result of making a change.

The cost and effort required for each classification is usually similar. Rules for materials, Labour and Machinery are based on the size of parts to be produced. The cost of materials for the small parts (headrest, armrest and bolsters) is similar. Equally, the cost of material for the medium parts (front seat backrest, front seat cushion, etc) is similar. The cost of material for the large parts is also similar. Labour and machinery costs are also determined by the size of parts for which estimate is required. Finally, bought out items incur the original cost agreed between the Tier 1 Suppliers and the Tier 2 Suppliers, as illustrated in section 4.3.5.

There are three types of foam moulding tools; Resin, Development, and Production. Each tool type is distinguished by the seat development stages (Trial-PT1, Pre-production-PT2 and Start of Production-SOP) and the capacity of products required. Resin tool is usually used at PT1 for trial parts only; this is the early stage of development. The Resin tool is made by adding resins together and is totally flexible. However, the tool can only be used to make 150 parts, after which its reliability and stability become low (see Table 6-3).

The benefits of using the Resin tool are its flexibility and its cost. The tool costs less than the other tools (Development and Production). Development tool is used at PT2 when product requirements are more refined and more details of product functionality are available. Production tool is more expensive and is not as flexible as the Development tool. Development and Production tools can be used to make up to

100,000 parts provided the wall thickness of the tools is still within range, 20mm for Development and 12mm for Production tool.

Rules 1 and 2 in Figure 6-3 and Figure 6-4 (also in Appendix D) presents sample rules. The first part of rule 1 shows the input parameters require to implement production at the PT1 using Resin tool for foam moulding; the volume of product required is not more than 150 individual parts and the current resin tool has not been used for more than 150 individual parts, wall thickness of current moulding tool must not be less than 6mm otherwise a new Development moulding tool is required.

Table 6-3: Foam moulding production tools

Resin Tool	Development Tool	Production Tool
4 weeks	8 weeks	10 weeks
Max 150 parts	Full production capacity	Full production capacity
Totally flexible	Medium scope for change	Not much scope for change
Flexible	20 mm wall thickness	12 mm wall thickness
Trial parts only	Trial parts and production	Trial parts and production

The cost of a new Resin tool is about €30,000, while the cost of modifying a Resin tool is €1,500 (provided the tool has not been used for more than 150 parts). The additional cost per piece (in bold - Rule 1) is determined by dividing the tool cost (new - €30,000 or modification - €1,500) by the capacity of tool - 150. Unlike Resin tools, which can only be used for trial parts, the Development moulding tool can be used for both trial parts and production parts. The flexibility of changing the tool is the only difference between Development and Production moulding tools. Development can be easily changed since it has approximately 20 mm wall thickness.

Tooling Rules

Tooling cost for foam

If pre-production stage = Trial Part (PT1)

Then **Resin Tool**

    If volume <= 150

        If resin tool usage is < 150

            Then Cost of tool modification = €1,500

            And cost on piece is (1,500/150) = **€10.00**,

        Else (New Resin tool required)

            Then Cost of new Resin tool = 30,000

            And cost on piece is (30,000/150) = **€200.00**

Else

If production stage = Pre-production (PT2)

Then **Development Tool**

    If volume <= 100,000

        If wall thickness >= 6mm

            Then Cost of tool modification = €8,000

            And cost on piece is (8,000/100,000) = **€0.80**,

        Else (New Development tool required)

            Then Cost of new Development tool = 100,000

            And cost on piece is (100,000/100,000) = **€1.00**.

Else

If production stage = SOP

Then **Production Tool**

    If volume <= 100,000

        If wall thickness >= 6mm

            Then Cost of tool modification = €10,000

            And cost on piece is (10,000/100,000) = **€0.10**,

        Else (New Production tool required)

            Then Cost of new Production tool = 200,000

            And cost on piece is (200,000/100,000) = **€2.00**.

Data required:

- Production stage
- Required volume of parts
- Various types of tool and cost
- Cost of each type of tool modification

Figure 6-3: Rule 1 - Tooling cost for foam

Rule 2 shows the tooling cost for the seat frame. The data required (input parameters) for the rules are status of current metal press (can it be modified for the proposed change or is a new tool required?), size of part to be made (see Figure 6-4), and total capacity required. These data (input parameters) are collected during a workshop session that needs to be conducted prior to a product development project. Regardless of the production stage, costs of parts are determined by their size.

Tooling Rules

Tooling cost for frame

If part = **Small**
- If 'can tool be modified' = yes
  - Then modify tooling cost = €10,000
    - And cost on piece is (10,000/100,000) = **€0.10**
  - Else (New tool required)
    - Then new tooling cost = €100,000
    - And cost on piece is (100,000/100,000) = **€1.00**

If part = **Medium**
- If 'can tool be modified' = yes
  - Then modify tooling cost = €15,000
    - And cost on piece is (15,000/100,000) = **€0.15**,
  - Else (New tool required)
    - Then new tooling cost = 150,000
    - And cost on piece is (150,000/100,000) = **€1.50**

If part = **Large**
- If 'can tool be modified' = yes
  - Then modify tooling cost = €20,000
    - And cost on piece is (20,000/100,000) = **€0.20**,
  - Else (New tool required)
    - Then new tooling cost = 200,000
    - And cost on piece is (200,000/100,000) = **€2.00**

Data Required:

Size of part

Tool capacity 100,000 piece

Figure 6-4: Rule 2 - Tooling cost for frame

The first part of Rule 2 shows that if a small part, such as the headrest, armrest or bolster is changed, and the current metal press tool can be modified then the incurred cost of tooling for frame is €0.10 i.e. cost of tool modification divided (€10,000) by total capacity of tool (100,000). If a new tool is required then the incurred cost of tooling for frame will be €1.00 i.e. cost of new tool (€100,000) divided by total capacity of tool (100,000).

Figure 6-2 indicates that there are 13 rules, two of the rules have been presented and the remaining 11 rules are in Appendix D.

Create delta time table for affected DPs (including external impact)
A relationship matrix is created to capture interlinks between the business drivers and design parameters. The entries in the matrix are actual incurred delay depending on the following factor:

Stage of production
Number of parts
Size of parts

Create delta cost table for affected DPs (including external impact)
A relationship matrix is created to capture interlinks between the business drivers and design parameters. The entries in the matrix are actual incurred cost depending on the following factor:

Stage of production
Number of parts
Size of parts

The delta cost of the proposed change will be the sum of all the affected design parameters. This concludes the internal impact analysis

6.3.2 External Cost Impact Analysis Methodology

Determine change origin
External cost impact analysis deals with the cost implications of requirement changes outside a system (i.e. within the entire vehicle). For example, how a change that

originates from the car seat affects the body-in-white. External cost impact analysis start with the determination of the change origin, any change will have an origin from one of the subsystems identified in Table 5-2 (Headrest, Backrest, Armrest, Cushion or Rail).

Table 6-4: System Matrix for Enterprise Impact Analysis

		1	2	3	4	5	6	7	8	9	10	11	12
		Seat	Body-in-white	Dashboard	Interior trim	Chassis	Brakes	Electricals	Electronics	Glass	Tyre	Powertrain	Cooling
1	Seat	0	x	x	x				x				
2	Body-in-white	x	0	x	x	x				x	x		
3	Dashboard	x	x	0	x			x	x	x			
4	Interior trim	x	x	x	0			x		x			
5	Chassis		x			0	x		x			x	
6	Brakes					x	0	x	x		x	x	
7	Electricals			x	x		x	0	x			x	x
8	Electronics	x		x		x	x	x	0			x	x
9	Glass		x	x	x					0			
10	Tyre		x				x				0	x	
11	Powertrain					x	x	x	x		x	0	x
12	Cooling							x	x			x	0

Generate propagation path

A systems matrix is created to illustrate the relationship between the mechanical systems of a car. The matrix in Table 6-4 illustrates the systems of a car; X is used to denote the relationship. The relationships between systems are identified and propagation path is generated:

Sys1 -> Sys2

Sys1 -> Sys3

Sys1 -> Sys4

Sys1 -> Sys8

The relationships above indicate that a change in the seat (Sys1) may potentially affect:

The body-in-white (Sys2),

The dashboard (Sys3),

The interior trim (Sys4), and

The electronics (Sys8)

The first three systems (body-in-white, dashboard and interior trim) will be considered for impact analysis as they are all mechanical components. However, electronics will not be considered for impact analysis as it is not a mechanical component.

Apply cost estimation rules

External impact analysis addresses question raised with regards to system interrelationship. If a change is required in the seat system how will this change affect the dashboard subsystem?

The rules in Figure 6-5 was created in a workshop session with cost estimators. The initial idea was proposed by the researcher and validated by a cost estimator. The rules show the relationships between the mechanical component of a car and the subsystems of a car seat. For example, a change that originates from the seat headrest, can potentially affect the body-in-white and interior trim. The point of impact of is the exact part of the body-in-white system (i.e. roof panel) that can be affected by a change to the headrest. Similarly, another point of impact for a change to the headrest is the fabric of the interior trim system.

Determine incurred cost on subsystem

The rules in Figure 6-5 also show the incurred cost on relevant subsystems. For example, a change that originates from the headrest is likely to incurred €50.00, if the body-in-white is affected. This is an estimate of what the cost estimator thinks it will cost to alter the roof panel of an individual car.

However, if the interior-trim is affected the potential cost of changing the interior trim will be €22.50, as illustrated in Figure 6-5. The cost estimator explained that the high cost is due to the fact that the worst case may be to change the entire fabric in the car.

External impact analysis summary

The external impact analysis summary will display the potential impact of a proposed change on all related external systems (i.e. systems external to the system for which the change if proposed, this scenario is further illustrated by the case study in the next section. This concludes the external impact analysis

External components affected

1. Body-in-white (headrest, rail)
2. Interior-trim (headrest, backrest, armrest, cushion)
3. Dashboard (backrest, armrest, cushion)
4. POI – point of impact

If change origin is headrest
    If body-in-white is affected
        Then POI is roof panel, cost is **€50.00**
    Else if interior-trim is affected
        Then POI is interior fabric, cost is **€22.50**

If change origin is rail
    If body-in-white is affected
        Then POI is floor panel, cost is **€50.00**
    Else if interior-trim is affected
        Then POI is interior fabric, cost is **€22.50**

If change origin is backrest
    If interior-trim is affected
        Then POI is interior fabric, cost is **€22.50**
    Else if dashboard is affected
        Then POI is steering wheel and instrument panel, cost is **€10.00**

If change origin is armrest
    If interior-trim is affected
        Then POI is interior fabric, cost is **€22.50**
    Else if dashboard is affected
        Then POI is steering wheel and instrument panel, cost is **€10.00**

If change origin is cushion
    If interior-trim is affected
        Then POI is interior fabric, cost is **€22.50**
    Else if dashboard is affected
        Then POI is steering wheel and instrument panel, cost is **€10.00**

Figure 6-5 : External Cost Impact Analysis Rules

6.4 Case Study 1: The Seating System (CIAM)

Analysis of Change Request

Two types of change scenarios are discussed in this section:

1 Constraints changing on requirements, and

2 Constraints changing on design parameters.

6.4.1 Example of Changes to the Seating System

The seating system exhibits requirement changes; these changes can be constraints changing on requirements (R) or constraints changing on design parameters (DP), as illustrated in Table 6-5. A list of sample changes to the seating system was elicited during an interview session Table 6-5.

Table 6-5: Examples of Changes to the Seating System

	Changes	**Systems/subsystems**	**Type of change**
1	Delete lumbar support	NA	DP
2	Add driver lifter	Interior Trim, Body-in-white, Dashboard	DP
3	Add driver armrest	NA	DP
4	Add driver and assistant seat back table	Rear seat	DP
5	Add driver and assistant seat back pocket	NA	DP
6	Add assistant seat back side pocket	Interior Trim, Body-in-white	DP
7	Add DVC inside cover	Interior Trim, Body-in-white, Dashboard	DP
8	Change cushion pad hardness		R
9	Change headrest shape	Body-in-white, interior trim	R
10	Change seat back shape	Headrest, cushion, lumbar	DP
11	Change seat cushion shape for tool space	Rail, seat back	DP
12	Add centre armrest with cup-holder	Seat back (major change i.e. new seat)	DP
13	Change fold down lever location shoulder	Seat back, cushion	R
14	Change seat cushion shape	Rail, seat back	R
15	Delete poly cover except driver seat	Cost reduction	R
16	Delete rear cushion buckle pocket	Cost reduction	DP
17	Change side air bag from standard to option (1)	Bought-in item, cost reduction	R
18	Change side air bag from standard to option (2)	Bought-in item, cost reduction	R

A Cost Engineer and a Design Engineer were interviewed, they were asked to describe examples of what is frequently changed in the seating system. Sometimes the changes proposed are either reduction of features or addition of features to the seat. For example, a change could be to change the headrest shape. It is important to note that a change to the headrest could have external impact on body-in-white. Another example of change is the addition of armrest to the assistant seat. The two types of changes: constraints changing on requirements and constraints changing on design parameters are discussed in the next section. The next section illustrates with the aid of examples from Table 6-5 how impact analysis is determined.

6.4.2 Scenario 1: Constraint Changing on Requirements

A requirement change is proposed:

INPUT:

Front Headrests

- 13mm is added to the top of the driver and passenger headrest to meet 750mm homologation dimension.

Business Driver Parameters

- Current tool is Development tool with 15mm wall thickness
- Total number of parts required is 100,000
- Fabric will have both straight and curved sewing lines
- Frames are made abroad

This is a change request from the specification tender. This change corresponds to the row 9 (change headrest shape) in Table 6-5, the change can potentially affect the body-in-white and the interior trim. This change will lead to seat headrest (i.e. the frame, foam and fabric) alteration. This change is related to R4 “The seat must be able to support occupant’s head” in Table 5-11. The propagation path for a change to R4 is shown in Table 6-6; this is determined by listing the strongly impacted requirements from the matrix. R2 and R5 are strongly impacted by a change to R4. However:

1. R2 is strongly impacted by R1, R3, R4, R7 and R8.

2. R5 is strongly impacted by R4.

By applying the stop criteria in identified in chapter 5, i.e. not more that two levels of propagation. The propagation path will be R1, R2, R3, R4, R5, R7 and R8.

Table 6-6: Requirements Affected by Changing R4 – The seat must be able to support occupant's head

R1	The seat must be able to support the occupant's lower body
R2	The seat must be able to support the occupant's upper body
R3	The seat must be able to support the occupant's arm
R4	The seat must be able to support the occupant's head
R5	The seat height must be adjustable
R7	The seat's upper body support angle must be adjustable
R8	The seat must provide additional support for the driver

The next step is to determine the associated design parameters from Table 5-12, the result is a worst case list of affected design parameters. Table 6-7 is a subsection of the requirements/design parameter matrix in chapter 5; it shows the design parameters that are related to the propagation path in Table 6-6. Table 6-8 is the worst case list of design parameters. An engineer extracts a subset of the worst-case list to derive most likely design parameters to be considered for cost impact analysis Table 6-9.

Table 6-10 presents a cost impact analysis summary of affected design parameters. The rules in Appendix D are used to determine the incurred cost and delay in time in relation to the business drivers.

Table 6-7: Design Parameters Associated to R4

		3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
		Seat belt bracket	Anti-submarine feature	Seat belt fabric	Power seat motor for recliner	Power seat motor for front lifter	Slide floor bracket	Front-Holder assembly -headrest, lock	Front-Holder assembly -headrest, free	Front-Finish assembly cushion, front seat right/left inner	Front-Finish assembly cushion, front seat right/left outer	Front-Knob -lifter level right/left	Front-Cover-reclining DVC, front seat right/left inner	Front-Knob -reclining DVC lever, right/left	Front-Cover-reclining DVC, front seat right/left inner	Front-Cover-seat slide rear inner right	Front-Cover-seat slide rear inner left	Front-Cover-seat slide rear outer right	Front-Cover-seat slide rear outer left	Front-Cover-seat slide front inner right	Front-Cover-seat slide front inner left	Front-Cover-seat slide front outer right	Front-Cover-seat slide front outer left	Power seat motor for slide	Headrest frame	Front seat backrest frame right/left	Front seat cushion frame right/left	Front armrest frame right/left	Slide seat rail	Headrest fabric	Front seat backrest right/left fabric	Front seat cushion right/left fabric	Front armrest right/left fabric	Headrest foam	Front seat backrest right/left foam	Front seat cushion right/left foam	Front armrest right/left foam
1	The seat must be able to support the occupant's lower body		x			x	x			x	x	x				x	x	x	x	x	x	x	x	x			x		x			x				x	
2	The seat must be able to support the occupant's upper body	x		x	x								x	x	x											x					x				x		
3	The seat must be able to support the occupant's arm																											x					x				x
4	The seat must be able to support the occupant's head							x	x																x					x				x			
5	The occupant must be able to adjust the height the seat can travel											x																									
7	The occupant must be able to adjust the seat-back angle												x	x	x																						
8	The occupant must be able to adjust the seat-back foam																									x					x				x		

Table 6-8: Worst-Case List of Affected Design Parameters

DP3	Seat belt bracket
DP4	Anti-submarine feature
DP5	Seat belt fabric
DP6	Power seat motor for recliner
DP7	Power seat motor for front lifter
DP8	Slide floor bracket
DP9	Front-Holder assembly -headrest, lock
DP10	Front-Holder assembly -headrest, free
DP11	Front-Finish assembly cushion, front seat right/left inner
DP12	Front-Finish assembly cushion, front seat right/left outer
DP13	Front-Knob -lifter level right/left
DP14	Front-Cover-reclining DVC, front seat right/left inner
DP15	Front-Knob -reclining DVC lever, right/left
DP16	Front-Cover-seat slide rear inner right
DP17	Front-Cover-seat slide rear inner left
DP18	Front-Cover-seat slide rear outer right
DP19	Front-Cover-seat slide rear outer left
DP20	Front-Cover-seat slide front inner right
DP21	Front-Cover-seat slide front inner left
DP22	Front-Cover-seat slide front outer right
DP23	Front-Cover-seat slide front outer left
DP24	Power seat motor for slide
DP25	Headrest frame
DP26	Front seat backrest frame right/left
DP27	Front seat cushion frame right/left
DP28	Front armrest frame right/left
DP29	Slide seat rail
DP30	Headrest fabric
DP31	Front seat backrest right/left fabric
DP32	Front seat cushion right/left fabric
DP33	Front armrest right/left fabric
DP34	Headrest foam
DP35	Front seat backrest right/left foam
DP36	Front seat cushion right/left foam
DP37	Front armrest right/left foam

Table 6-9: Subset of DPs Related to R4

DP3	Seat belt bracket
DP4	Anti-submarine feature
DP5	Seat belt fabric
DP9	Front-Holder assembly -headrest, lock
DP10	Front-Holder assembly -headrest, free
DP25	Headrest frame
DP26	Front seat backrest frame right/left
DP27	Front seat cushion frame right/left
DP28	Front armrest frame right/left
DP30	Headrest fabric
DP31	Front seat backrest right/left fabric
DP32	Front seat cushion right/left fabric
DP33	Front armrest right/left fabric
DP34	Headrest foam
DP35	Front seat backrest right/left foam
DP36	Front seat cushion right/left foam
DP37	Front armrest right/left foam

6.4.3 Business Diver Distribution Graph

Table 6-10 is further analysed to understand the distribution of costs and time among the business drivers. From the pie chart in Figure 6-6 and the bar chart in Figure 6-7 it is observed that raw materials will incur the highest cost, 29% of total incurred cost. This kind of information is particularly useful for feasibility and economic decision-making process at the early stages of requirements change implementation. The cost of bought out items (22%) and machinery (22%), can also be considered to be of concern.

Similarly Figure 6-8 and Figure 6-9 show that more time is required for changes that affect machinery on the headrest. This means that changes that will attract high machinery delay should be avoided. Labour in both graphs is negligible.

Table 6-10: Cost Impact Analysis Summary

			Cost											Time					
	Affected DPs	**Size**	Old Cost		**Tooling**	**Raw Material**	**Labour**	**Machinery**	**Bought Out**		**Delta Cost**	**% inc**		**Tooling**	**Raw Material**	**Labour**	**Machinery**	**Bought Out**	**External Impacts**
DP3	Seat belt bracket		€ 5.00						€ 5.00		**€ 5.00**	100.00						2 weeks	
DP4	Anti-submarine feature		€ 5.00						€ 5.00		**€ 5.00**	100.00						2 weeks	
DP5	Seat belt fabric		€ 5.00						€ 5.00		**€ 5.00**	100.00						2 weeks	Interior trim
DP9	Front-Holder assembly -headrest, lock		€ 2.00						€ 2.00		**€ 2.00**	100.00						2 weeks	
DP10	Front-Holder assembly -headrest, free		€ 2.00						€ 2.00		**€ 2.00**	100.00						2 weeks	
DP25	Headrest frame	small	€ 10.00		€ 1.00	€ 2.50	€ 1.00	€ 1.25			**€ 5.75**	57.50		5 weeks	1 week	30 sec	6 months		Dashboard
DP26	Front seat backrest frame right/left	medium	€ 25.00		€ 1.50	€ 3.00	€ 1.50	€ 1.25			**€ 7.25**	29.00		6 weeks	1 week	40 sec	6 months		Dashboard
DP27	Front seat cushion frame right/left	medium	€ 20.00		€ 1.50	€ 3.00	€ 1.50	€ 1.25			**€ 7.25**	36.25		6 weeks	1 week	40 sec	6 months		Dashboard
DP28	Front armrest frame right/left	small	€ 10.00		€ 1.00	€ 2.50	€ 1.00	€ 1.25			**€ 5.75**	57.50		5 weeks	1 week	30 sec	6 months		
DP30	Headrest fabric	small	€ 5.00		€ 0.50	€ 1.00	€ 0.50	€ 1.25			**€ 3.25**	65.00		30 sec	1 week	30 sec	1 week		Interior trim
DP31	Front seat backrest right/left fabric	medium	€ 15.00		€ 1.50	€ 1.50	€ 0.75	€ 1.25			**€ 5.00**	33.33		50 sec	1 week	40 sec	1 week		Interior trim
DP32	Front seat cushion right/left fabric	medium	€ 10.00		€ 1.50	€ 1.50	€ 0.75	€ 1.25			**€ 5.00**	50.00		50 sec	1 week	40 sec	1 week		Interior trim
DP33	Front armrest right/left fabric	small	€ 5.00		€ 1.00	€ 1.00	€ 0.50	€ 1.25			**€ 3.75**	75.00		30 sec	1 week	30 sec	1 week		Interior trim
DP34	Headrest foam	small	€ 10.00		€ 0.80	€ 2.00	€ 0.50	€ 2.00			**€ 5.30**	53.00		4 weeks	1 week	30 sec	8 months		
DP35	Front seat backrest right/left foam	medium	€ 25.00		€ 0.80	€ 2.50	€ 0.75	€ 2.67			**€ 6.72**	26.88		4 weeks	1 week	40 sec	8 months		
DP36	Front seat cushion right/left foam	medium	€ 10.00		€ 0.80	€ 2.50	€ 0.75	€ 2.67			**€ 6.72**	67.20		4 weeks	1 week	40 sec	8 months		
DP37	Front armrest right/left foam	small	€ 10.00		€ 1.00	€ 2.00	€ 0.50	€ 2.00			**€ 5.50**	55.00		4 weeks	1 week	30 sec	8 months		
	Total cost incurred		€ 174.00		€ 12.90	€ 25.00	€ 10.00	€ 19.34	€ 19.00		**€ 86.24**	49.56		6 weeks	1 week	40 sec	8 months	2 weeks	

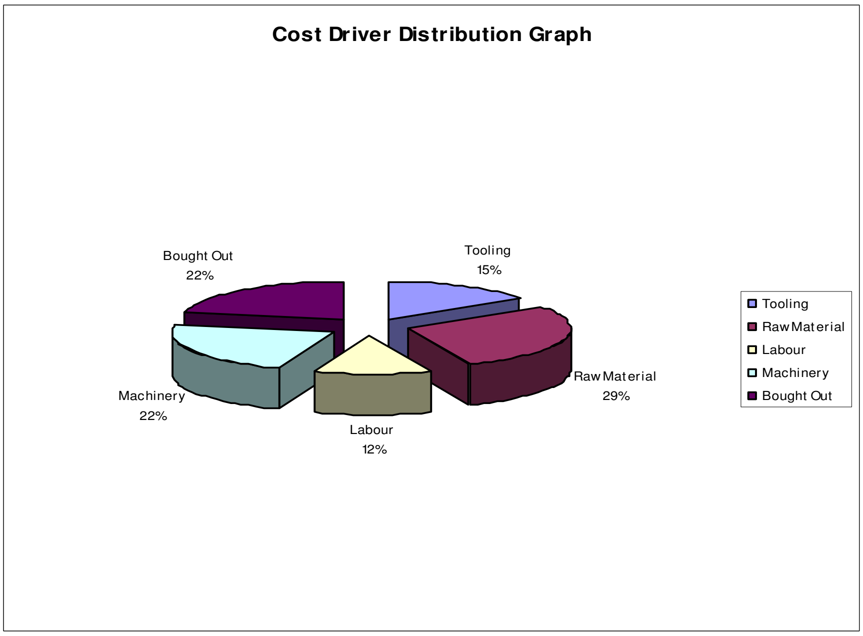


Figure 6-6: Cost Driver Distribution Pie Chart

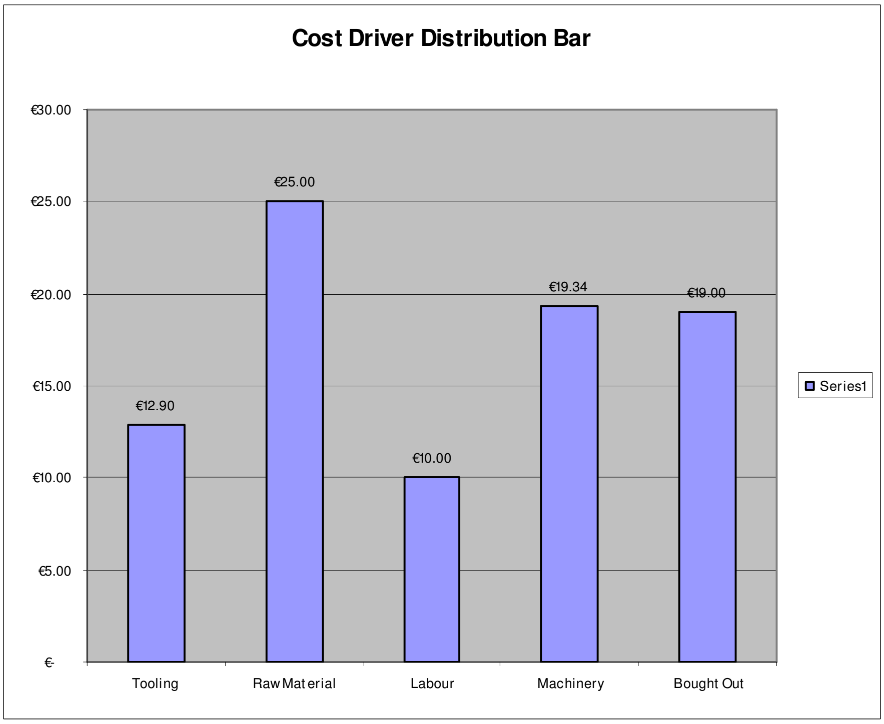


Figure 6-7: Cost Driver Distribution Bar Chart

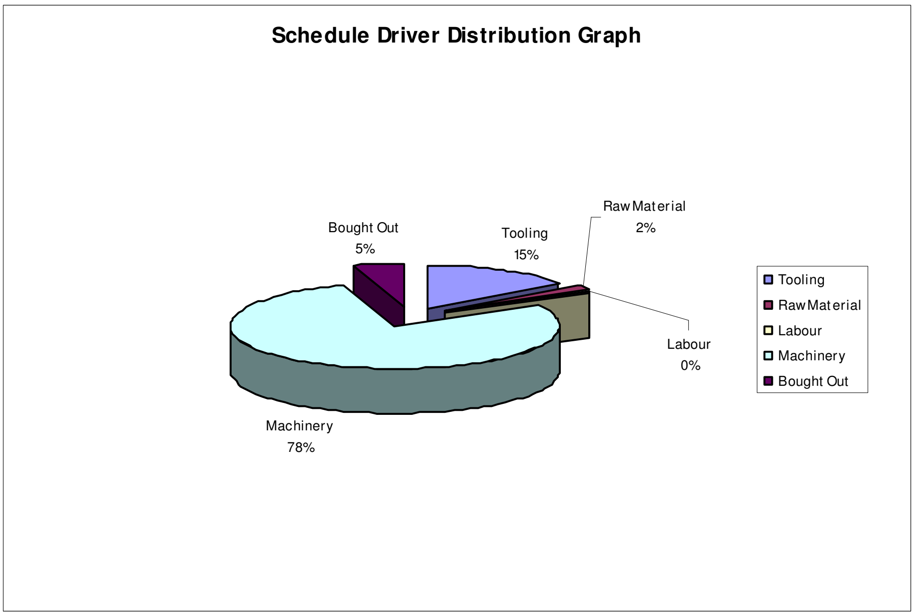


Figure 6-8: Time Driver Distribution Pie Chart

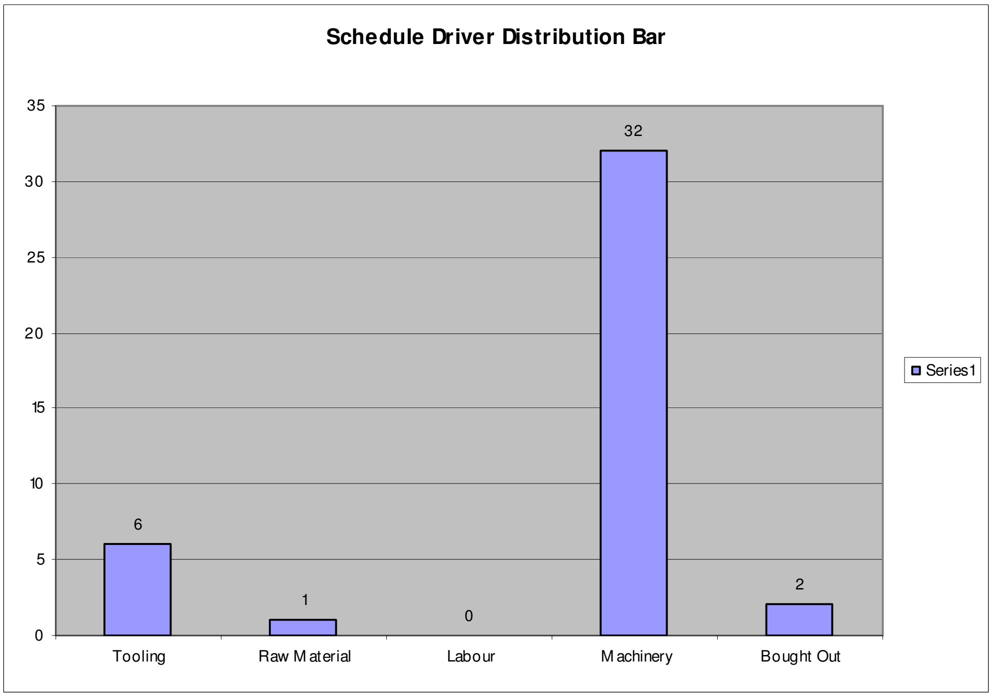


Figure 6-9: Time Driver Distribution Bar Chart

External Cost Impact Analysis for Constraints Changing on Requirements

The external impact analysis rule in Figure 6-5 and Appendix D are used to determine the external impact of a proposed change that affected R4 "The seat must be able to support occupant's head. The first step is to determine the origin of the change, in this case the headrest's component; frame, fabric and foam. As illustrated in Table 5-10, Figure 6-5 and Appendix D, the following external (to seating system) systems are impacted by a change to the headrest (i.e. external impact propagation path):

Body-in-white, and
Interior trim

As illustrated in the rules:

- A change originating from the headrest that affect the body-in-white will cost €50.00 and the point of impact is roof panel
- A change originating from the headrest that affects the interior trim will cost €22.50 and the point of impact is the interior trim fabric

The cumulative cost for external impact can potentially be the sum of €50.00 and €22.50. The result is €72.50.; this amount represents a worst case scenario. This external cost impact analysis aims to provide a high-level view of potential impact when a change request is implemented. The rules are applicable to a changes relating to the seat system.

It is important to point out that these results are indicative cost to help OEM and Suppliers to decide whether or not to go ahead with a proposed change.

6.4.4 Scenario 2: Constraint Changing on Design Parameters

As shown in Table 6-5, constraints changing on design parameters are those changes that affect design parameters directly. For example, a design parameter change is proposed:

INPUT:

<u>Front Seat</u>

- Add lifter to front passenger seat

<u>Business Driver Parameters</u>

- Current tool is Development tool with 15mm wall thickness
- Total number of parts required is 100,000
- Fabric will have both straight and curved sewing lines
- Frames are made abroad

This change corresponds to row 2 in Table 6-5, the change can potentially affect the body-in-white and the interior trim. This change will mainly affect the seat cushion and seat rail, as the lifter and rails are attached to the seat cushion. The change is directly related to:

- DP4,
- DP8,
- DP11,
- DP13,
- DP27,
- DP29,
- DP32 and
- DP36

This is illustrated in Table 5-13. Direct relationship here means that the listed DPs are parts of the seat directly connected with the lifter. There are also some DPs that are indirectly related to the direct DPs, these are also identified from Table 5-13, i.e. DP1, DP5, DP12, DP30, DP31 and DP33. The propagation path for a change to the lifter is shown in Table 6-11; this is a worst case list of affected design parameters, there are 14 DPs in total (listed serially in Table 6-12).

Table 6-11: Design Parameters Related to Lifter

		DP1	DP4	DP5	DP8	DP27	DP29	DP30	DP31	DP32	DP33	DP36
		Seat heating mechanism	Anti-submarine feature	Seat belt fabric	Slide floor bracket	Front seat cushion frame right/left	Slide seat rail	Headrest fabric	Front seat backrest right/left fabric	Front seat cushion right/left fabric	Front armrest right/left fabric	Front seat cushion right/left foam
DP4	Anti-submarine feature		**0**			X						X
DP8	Slide floor bracket				**0**		X					
DP11	Front-Finish assembly cushion, front seat right/left inner											
DP12	Front-Finish assembly cushion, front seat right/left outer											
DP13	Front-Knob -lifter level right/left											
DP27	Front seat cushion frame right/left	X	X			**0**				X		X
DP29	Slide seat rail				X		**0**					
DP32	Front seat cushion right/left fabric	X		X		X		X	X	**0**	X	X
DP36	Front seat cushion right/left foam	X	X			X				X		**0**

Table 6-12: Worst-Case List of DPs Related to Headrest Frame

DP1	Seat heating mechanism
DP4	Anti-submarine feature
DP5	Seat belt fabric
DP8	Slide floor bracket
DP11	Front-Finish assembly cushion, front seat right/left inner
DP12	Front-Finish assembly cushion, front seat right/left outer
DP13	Front-Knob -lifter level right/left
DP27	Front seat cushion frame right/left
DP29	Slide seat rail
DP30	Headrest fabric
DP31	Front seat backrest right/left fabric
DP32	Front seat cushion right/left fabric
DP33	Front armrest right/left fabric
DP36	Front seat cushion right/left foam

A design engineer now selects a subset from the worst case list in Table 6-12, the purpose of this task is to select the most relevant design parameters for cost analysis Table 6-13. Similar to scenario 1 of the seating system, the incurred cost is determined by identifying values from the cost and time rules in Appendix D. For example, Rule 1, if the part to be changed is the anti-submarine feature, the potential cost of the change with regards to the bought-out item cost driver is €5.00 (DP4). The rules are used in a similar fashion to identify the incurred cost on each cost driver and time driver for each item in the list of affected design parameters Table 6-14. All of the affected DPs are bought out items.

Table 6-13: Selected List of DP for Lifter Addition

DP4	Anti-submarine feature
DP8	Slide floor bracket
DP11	Front-Finish assembly cushion, front seat right/left inner
DP12	Front-Finish assembly cushion, front seat right/left outer
DP13	Front-Knob -lifter level right/left
DP29	Slide seat rail

6.4.5 Business Driver Distribution Graphs

No graph is plotted for this scenario since there is only one business driver involved.

Table 6-14: Cost Impact Analysis Summary for Changes Related to Headrest Frame

		Cost											Time					
	Affected FRs and DPs	Old Cost		**Tooling**	**Raw Material**	**Labour**	**Machinery**	**Bought Out**		**Delta Cost**	**%i inc**		**Tooling**	**Raw Material**	**Labour**	**Machinery**	**Bought out**	**External Impacts**
DP4	Anti-submarine feature	€ 5.00						€ 5.00		**€ 5.00**	100.00						2 weeks	
DP8	Slide floor bracket	€ 6.00						€ 6.00		**€ 6.00**	100.00						2 weeks	Body-in-white
DP11	Front-Finish assembly cushion, front seat right/left inner	€ 4.00						€ 4.00		**€ 4.00**	100.00						2 weeks	
DP12	Front-Finish assembly cushion, front seat right/left outer	€ 4.00						€ 4.00		**€ 4.00**	100.00						2 weeks	
DP13	Front-Knob -lifter level right/left	€ 3.50						€ 3.50		**€ 3.50**	100.00						2 weeks	Interior trim
DP29	Slide seat rail	€ 8.00						€ 8.00		**€ 8.00**	100.00						2 weeks	Body-in-white
		€ 30.50						€ 30.50		**€ 30.50**	100.00						2 weeks	

External Cost Impact Analysis for Constraints Changing on Design Parameters

Similar to the external cost impact analysis for constraints changing on requirements, this section determines the external impact of a proposed change due to changes made to the seat lifter. The first step is to determine the origin of the change; the lifter is part of the seat cushion. From Figure 6-5, the following external (to seating system) systems are affected by a change originating from the seat cushion:

- Interior trim, and
- Dashboard

As illustrated in the rules:

- A change originating from the cushion that affects the interior trim will cost €22.50
- A change originating from the cushion that affect the dashboard will cost €10.00

The cumulative cost for external impact can potentially be the sum of €22.50 and €10.00. The result is €32.50. This external cost impact analysis aims to provide a high-level view of potential impact when a change request is implemented.

6.5 Validation of CIAM

A validation workshop was held at the Tier 1 Supplier organisation. This workshop was between the Project Cost Manager (a cost estimator with 5 years experience in the automotive industry) and the researcher (the author of this thesis). This workshop was divided into two sessions, the workshop lasted a whole day:

The focus of the first session was to validate the cost and time rules, including the external rules. Several changes were proposed by the cost estimator:

- Such as the inclusion machinery rules, prior to the workshop the researcher identified 4 business drivers. The cost estimator mentioned that the machinery manufacturing time does not change as it takes a long time to get the right machinery made. A typical manufacturing time for the machinery can be 18 months.

- The classification of parts into small medium and large was also validated, the cost estimator confirmed that the classification is a true reflection of how his organisation views the parts.

The cost estimator was not able to give exact cost data due to confidentiality and sensitive nature of cost estimation data.

The second session validated inputs to the methodology and the incorporation of feedbacks from the second workshop. One of the results of the second session was the collection of sample requirement changes and the classification of changes to 1) constraints changing on requirements and 2) constraints changing on design parameters.

6.6 Key Observations

The cost estimation of design requirement changes requires collaboration between an OEM and its Tier 1 suppliers. In modern complex part manufacturing industries, like automotive and aerospace, a large proportion of parts are designed and manufactured by suppliers. These suppliers hold the real manufacturing knowledge about the parts. OEM needs to create long term partnership and conducive business environment where the Tier 1 Suppliers would be happy to share the cost related rules and the mapping between requirements and design parameters. In turn Tier 1 Suppliers need to develop similar relationship with their own suppliers.

- The first part of the methodology, where R/R and R/DP matrices are defined, is time consuming. This is a knowledge intensive task and requires designers and design managers from the supplier.
- Once the matrices are captured for a product and the cost rules are defined, estimating cost of any requirement change can be highly resource effective.
- There is a need to refine the methodology to reuse the matrices and the rules

for other products in the same family.

- It is envisaged that a reuse of the cost impact analysis methodology for another system (e.g. cooling system) will require approximately 14 man-hours. Chapter 7 explain this assumption further by validating CIAM with a second OEM-Tier 1 supplier collaboration.
- The complexity level of propagation path may be an issue, since there is the tendency for a change to ripple indefinitely through the system. This issue can be resolved with the use of stop criteria.
- A bottleneck with the use of this methodology is the availability of relevant stakeholders, but the time required for the reuse of the methodology can be incorporated into the integrated product team meetings.

6.7 Summary

This chapter presented and detailed the development of a cost impact analysis methodology for requirement changes of mechanical design product in the automotive industry. The methodology is particularly useful during conceptual design phase. The application of cost impact analysis methodology can be generic across a module (seating system) product range or across the automotive industry. For example, the case study above is for the driver seat. Another application can be the assistant seat or the rear seat. There is not much difference between the driver seat and the assistant seat. In most cases the assistant seat has fewer features compared to the driver seat.

The research has identified a lack of formal methodology to assess cost of a requirement change. The research has demonstrated that the cost impact analysis can be addressed in two stages: first by identifying the design parameters that are affected and then second by predicting incurred cost for possible design changes using a rule based approach. Impact on design parameters are identified through a set of matrices. The impact analysis can handle designs with couplings between requirements and design parameters, as explained in chapter 5. The methodology is illustrated in an automotive application.

CIAM is further validated with the cooling system in the next chapter.

7 FURTHER CASE STUDY

7.1 Introduction

In chapter 4, the author identified the need for a methodology that can improve the cost estimation of requirement changes at the early stage of product design within the automotive industry. In chapter 5, an extraction methodology was created to extracts relevant data from product documentation such as request for quotation, specification tender, bill of materials, etc. In chapter 6, a cost impact analysis methodology was created to estimate the incurred cost of implementing requirement changes, the methodologies was applied to a case study. This chapter validates the methodologies in chapter 5 and chapter 6 with another case study and compares the result of both case studies. Therefore the aim of this chapter is:

Chapter Aim:

To demonstrate that the methodologies developed in chapter 5 and chapter 6 can be applied to another case study and to investigate generality of both methodologies.

The first case study (in chapter 5 and chapter 6) was developed with a major OEM and a Tier 1 supplier. The objective was to prove that incurred cost of requirement changes for automotive mechanical components could be structured. The second case study was developed in collaboration between another OEM and one of its Tier 1 Supplier. The objective was to investigate how CIAM will behave in another OEM/Tier 1 Supplier relationship for a different product. The two case studies are automotive systems that play relatively important roles in the life of a car. Both are mechanical product with many complex parts.

The rest of the chapter is structured as follows. Section 7.2 describes the cooling system. Section 7.3 applies the extraction methodology on the cooling system to extract relevant data. Section 7.4 applies the cost impact analysis methodology on the cooling system. Section 7.5 discusses the validation of the cooling system case study. Independent expert validation is provided in section 7.6. Key observations are shown in section 7.7, before the summary in section 7.8.

The seating system was used to create EXTRAM and CIAM; the results were satisfactory and encouraging. The two methodologies are extended to a second case study as discussed in the next section.

7.2 Case Study 2: The Cooling System

The cooling system has been chosen for the second case study. This case study was developed in collaboration between a second OEM and one of its Tier 1 Suppliers. The OEM specialises in luxury vehicles. Two experts were interviewed for the purpose of the case study: a cost estimator with 2 years experience and a design engineer with 4 years experience.

The engine in the car runs best at a high temperature. When the engine is cold, components wear out faster, and the engine is less efficient and emits more pollution. Therefore, the primary function of the cooling system is to allow the engine to heat up as quickly as possible, and then to keep the engine at a constant temperature.

Most of the energy in the car fuel (perhaps 70%) is transformed into heat, and it is the job of the cooling system to take care of that heat. In fact, the cooling system on a car driving down the motorway dissipates enough heat that can heat two average-sized homes. The cooling system also keeps the engine from overheating by transferring this heat to the surrounding air.

The radiator is usually made of aluminium; it has fins that run the length of the radiator. The radiator is connected to the engine through hoses. These hoses allow cooling fluid to flow back and forth between the engine and the radiator. Expansion tank (Cooling fluid reservoir) holds fluid and is expanded when the engine becomes hot. The cooling system also has a fan that blows air onto the radiator in order to cool it.

In order to make both extraction methodology (chapter 5) and cost impact analysis methodology (also in chapter 5) generic for mechanical components of the automotive industry, a second OEM and Tier 1 Supplier has been selected for the evaluation of the methodologies described in chapter 5. The choice is partly due to the interest of the second OEM and one of their Suppliers to resolve the issues explore in Chapter 4.

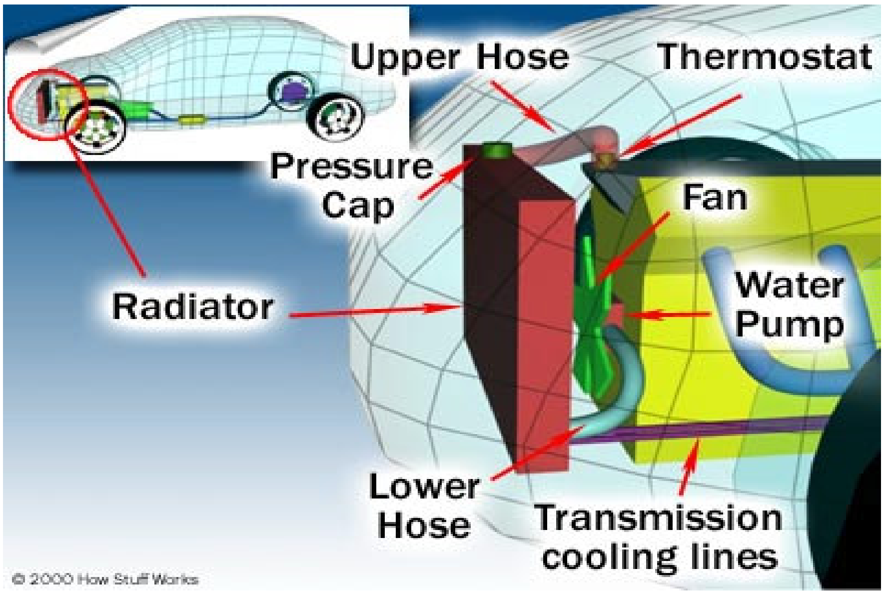


Figure 7-1: Cooling System (Nice, 2004)

7.3 Application of REXTRAM on the Cooling System

REXTRAM and CIAM are validated by the cooling system (a second case study). The purpose of this section is to fulfil the aim of this chapter i.e. to demonstrate that the methodologies developed in chapter 5 and chapter 6 can be applied to another case study and to investigate generality of both methodologies.

7.3.1 Domain Analysis

A design specification is specific to a system that is supplied by one or more suppliers. Design specification specifies the engineering requirement. A design specification on car cooling system is for a specific purpose "Mechanism for cooling the engine of the car".

There are many types of cooling system Figure 7-1; transmission, air conditioner, power steering, etc. The car cooling system is modular. This can be easily identified from the product design specification. The cooling system can be divided into 6 subsystems:

- Radiator
- Hoses
- Expansion tank
- Thermostat
- Water pump
- Fan

All six subsystems are interrelated. For example, Table 7-1 uses a matrix to illustrate the relationship between the subsystems in the cooling system. If the diameter of the radiator spigot is increase the diameter of the hose connected to the radiator will need to be increased. Table 7-1 forms the prelude to External Cost Impact Analysis in section 7.5.

Table 7-1: Subsystem Relationship Matrix for the Car Cooling System

	Hoses	Radiator	Expansion tank	Thermostat	Water pump	Fan
Hoses	0	X	X	X	X	
Radiator	X	0	X			X
Expansion tank	X	X	0			
Thermostat	X			0		X
Water pump	X				0	
Fan		X		X		0

Table 7-1 depicts the relationships between the subsystems of a cooling system. The cooling system case study is applied to both methodologies developed in chapter 5 (relevant data extraction methodology) and chapter 6 (cost impact analysis methodology). This section describes the relevant data extraction process.

Similar to the seat system the Product Design Specification document of the Second OEM is an agreement between them and a Tier 1 supplier. For this OEM, the development of their cars involves first determining the market positioning, product characteristics and production volume. The specification of their cars proceeds in the following way:

- Breaking down the product (car) into systems (cooling, breaks, seat, etc). Each system represents a specification and is in turn decomposed further.
- Translating the specifications into functional requirements and design parameters that are measurable and verifiable via there constraints.

The OEM generates the product requirements, in terms of functionality, performance and cost targets. This information is communicated to a Tier 1 Supplier, who will then realise the system by conducting detailed engineering.

7.3.2 Identification of Relevant Documents

This section details the steps involved in decomposing the diverse design documents Figure 7-2 to requirements, design parameters and constraints. These documents do not necessarily articulate all requirements, design parameters and their constraints. Therefore, it is the job of the Change Request Analyst to identify requirements, design parameters, and their constraints by functionally decomposing the cooling system and related documentation Figure 7-2. Table 1 contains example of product documents that can yield various components.

Figure 7-2 can be categorized under six headings similar to that of the seat system:

Conceptual
Vehicle Program Plan

Design
Statement of Work
Design Note
Assemble Drawing

Parts
Parts List
Bill of Materials

Specification

Product Design Specification

Component Design Specification

System Design Specification

Functional Specification

Quotation

Request for Quotation

Quotation Analysis Form

Homologation

DIN Standard

Similar to the seat system case study, the documents in Table 7-2 have been selected due to access and availability. Relevant data was extracted from the listed document as illustrated in the subsequent sections.

Table 7-2: List of Selected Document

Documents	Data extracted
DIN standards	Design parameters and their constraints
Quotation Analysis Form	Design parameters
Request for Quotation	Business requirements
Product Design Specification	Requirements, Design parameters and their constraints
Bill of Materials	Design parameters only
Functional Specification	Requirements, Design parameters and their constraints

Requirements and Design parameters

Requirements, design parameters, constraints and cost estimation rules can be extracted from several documents, Figure 7-2. For the purpose of this research, several documents are used including request for quotation, specification tender and bill of materials, samples of these documents are provided in Appendix E. When analysing the information in these document four questions are asked, is the information (similar to chapter 5):

5. What must the system do – Requirements
6. How must the system achieved (1) – Design parameters
7. What are the bounds on (1) – Requirements constraint
8. What are the bounds on (2) – Design parameters constraint

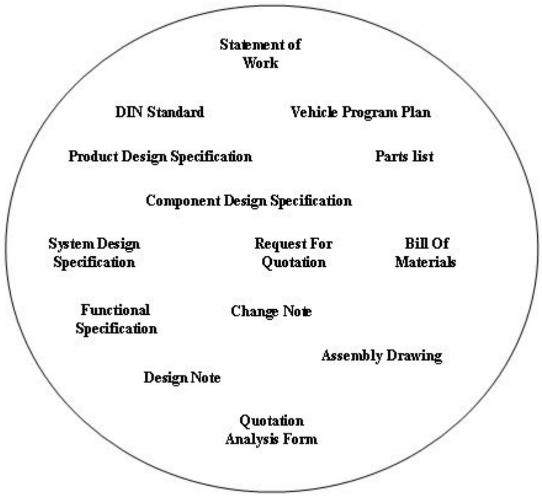


Figure 7-2: Documentation Sources (Cooling System)

7.3.3 Identification of Relevant Text

DIN Standards

DIN standard is the German Industrial Norm for industrial products. DIN standards may contain design parameters and their constraints. DIN standards also contain general product information such as dimensions, material properties, and warning, relative to the use of the product. Table 7-3 illustrates an example of design parameters and their constraints. Hose is a design parameter with internal diameter and wall thickness as constraints. Spigot is a design parameters related to radiator. External diameter and bead diameter are constraints on spigot.

Table 7-3: Dimensions Table

Hose			Spigot			
Internal diameter		Wall thickness	External diameter		Bead diameter	
di	Limit dimension	p	ds	Limit dimension	dw	Limit dimension

Quotation Analysis Form

Quotation Analysis Form (QAF) contains the cost breakdown of the cooling system. QAF is especially useful for cost estimation rules; it also contains the business drivers (cost and time drivers) including design parameters. Table 7-4 shows extracts from a QAF. The key business divers that can incur cost or time impacts are also shown in Table 7-4: Procured parts are pre assembled parts that are usually supplied by Tier 2 suppliers. Raw materials are required for the realisation of the cooling system components.

Table 7-4: Extracts from Quotation Analysis Form

Business Driver	
1	Procured Parts
2	Raw Material
3	Process Costs
4	Other Costs
5	Tooling Cost
6	Logistics
TOTAL OFFER PRICE	(1)+(2)+(3)+(4)+(5)+(6)

Process costs are the labour and machinery costs. Other costs are general overheads, design and development cost. Tooling cost contains the breakdown of the cost of tools required for the cooling system. Finally, logistics is made up of transport, sequencing and warehousing. Logistics and other business drivers will not be considered for further analysis.

Request for Quotation

2. Specific pricing and delivery information on listed products or services. Quotations are requested for exact quantities and products may be specified by make/model number, batch number, and industry specification. For example, "X250 is positioned in the large Premium Car segment to compete worldwide with BMW 5 Series, Mercedes Benz E Class, Lexus GS300/430, and Audi A6".
3. A written quotation or bid from an approved or qualified supplier, used for purchases of goods and services where criteria including service, quality, quantity, delivery, will be evaluated as well as price. For example, "The planned peak year volume is 43,000 vehicles. The Supplier may be asked to quote for alternative volume, body and style scenarios".

Product Design Specification

Specification sets the required characteristics to be considered for award of contract, including sufficient detail to show how the product is to be manufactured. Usually contains requirements, design parameters and their constraints.

6.3.6 Coolant Circuit Service Drain and Fill Procedure

Fast Fill

The complete procedure should take no longer than 5 minutes including any engine running time. No road test should be required. *It should be simple to fill without causing spillage on the floor, and any local spillage on the bodywork should be easy to clean.*

Figure 7-3: Extracts from Product Design Specification (a)

The highlighted text in Figure 7-3 is an example of functional requirement. 'It should be simple to fill the cooling system without causing spillage on the floor, and any local spillage on the bodywork should be easy to clean'.

7.1 Coolant Level Assessment

The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap

7.2 Coolant Top Up

Coolant top up should be simple, safe, and clean for 5^{th} to 95^{th} percentile of people, without the need for tools or special containers.

Figure 7-4: Extracts from Product Design Specification (b)

Figure 7-4 is another example of requirements extractions. The figure contains two requirements, as shown below:

- R11 – The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap
- R12 – Coolant top up should be simple, safe, and clean for 5th to 95th percentile people, without need for tools or special containers
-

Table 7-5: Extract from Bill of Materials

Item	Ford Item No	Description	Quantity
CVEF256		Engine fan	1
CVCE256		Expansion tank	1
PGG500161	5H22- 8600-AA	Fan assembly-cooling	1
PCN500040		Frame-cooling system	1
PCH501300		Hose assembly-expansion tank coolant	1
PCH501780		Hose assembly-radiator to expansion tank bleed	1
PCH502080		Hose-cooling system bleed	1

7.3.4 Bill of Materials

Bill of materials (BOM) is the list of the components necessary to make a part or product and the amount of each component required, usually contains design parameters only. Table 7.5 is an example of design parameters within the BOM

Functional Specification

Functional specification is a document that describes in detail the characteristics of the product with regard to its intended features and defines the functions that a system or system component must perform. Usually contains requirements, design parameters and their constraints. Figure 7-5 illustrates two constraints on design parameters: inner diameter of hose and outer diameter of hose.

2.1 Terms of Reference

ID – Inner Diameter of hose
OD – Outer Diameter of hose

Figure 7-5: Extracts from Functional Specification (a)

Hose characteristics are shown in Figure 7-6. For example, the Mandrel is machinery used for making hoses, the oven is a tool used for curing the hose. The mandrel here is a cost driver that can significantly affect the cost of the total cost of the cooling system. The oven is a cost driver as well; however, it is a tool since it can be used for any number of components and customers.

Table 7-6: Repository for Requirements, Requirement Constraints, Design Parameters and Design Parameter Constraints

Subsystem		Functional requirements	Constraints	External impact		Design parameters	Constraints	External impact
Hoses	R1	The CS should allow fluid to flow from one subsystem to the other	flow rate, hose length, inner diameter, outer diameter	engine	DP1	Hose-cooling system bleed (30cm)	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
	R2	The CS material must facilitate heat conservation	hose thickness, hose material		DP2	Hose-engine coolant valve (35cm) 2 bends	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
	R3	The clearance distance between the hose and other parts should not be less than 25mm	25mm, hose diameter, hose length	engine, body-in-white	DP3	Hose-engine to oil cooler coolant (40cm) 2 bends	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP4	Hose-expansion tank coolant (40cm) 2 bends	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP5	Hose-expansion tank to pump coolant (35cm)	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP6	Hose-four way connector (30cm) 3 bends	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP7	Hose-oil cooler to rail coolant (35cm)	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP8	Hose-radiator to thermostat coolant (30cm)	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP9	Bracket-oil pipe mounting		
					DP10	Clip - pipe	tension force	
					DP11	Clip-coolant hose	tension force	
					DP12	Clip-spring band	tension force	
					DP13	Pipe-oil cooler to transmission (30cm)	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP14	Pipe-transmission to oil cooler (35cm)	flow rate, hose length, inner diameter, outer diameter, thickness, material	Engine
					DP15	Clip-hose (semi std part)	tension force	
Radiator	R4	The CS must facilitate heat exchange with the environment	fin length, fin pitch, number of fin layers, tube length, tube diameter	grill, bumper	DP16	Mount-radiator rubber	material	Grill, bumper, engine
	R5	There should be no leakage between system components	interferance 1mm, clip range	engine, radiator	DP17	Bracket-radiator mounting (lh)		Grill, bumper, engine
					DP18	Bracket-radiator mounting (rh)		Grill, bumper, engine
	R6	The radiator will be free from cosmetic corrosion during the first 3 years of ownership	radiator material		DP19	Condenser assy-air conditioning	fin length, fin pitch, number of fin layers, tube length, tube diameter, spigot external diameter, spigot bead diameter	Grill, bumper, engine
					DP20	Frame-cooling system		Grill, bumper, engine
					DP21	Radiator-cooling system (fins, tubes, endtanks)	fin length, fin pitch, number of fin layers, tube length, tube diameter, spigot external diameter, spigot bead diameter	Grill, bumper, engine
Expansion tank	R7	The CS must have a mechanism for relieving pressure			DP22	Cap-expansion tank pressure	1.1 bar	
	R8	The CS must facilitate temperature elevation (cold start)			DP23	Expansion tank	capacity, 10 bar burst endurance	
	R9	The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap						
Thermostat	R10	The CS must be able to control heat temperature	sensor, wax element	interior trim	DP24	Housing-thermostat	temperature range 82-103 degree C	
					DP25	Thermostat sensor	sensor, wax element	
Water pump	R11	The CS must circulate fluid through the engine	pump	engine	DP26	Pump	flow rate, pressure	Engine
Fan	R12	The CS must draw outside air into the engine compartment to cool the engine	fan speed, air duct, cowl shape	grill, bumper	DP27	Cowl-cooling system fan	package space	Body-in-white
	R13	The CS must ensure that there is no internal recirculation within the cooling pack under most conditions	cowl shape	grill, bumper, body-in-white	DP28	Engine fan	air flow performance, blade profile, fan diameter, fan speed	Grill, bumper, body-in-white

7.3 Hose Forming

7.3.1 Application Type List

- Load Hose to Mandrel
- Cure Hose in Oven
- Unload Hose from Mandrel
- Trim Hose to Finished Length

Figure 7-6: Extracts from Functional Specification (b)

The result of the extraction process is summarised in Table 7-6, the requirements, design parameters, constraints, including externally impacted systems are illustrated. This section has described how the relevant data can be extracted from a mirage of documents. The next section uses the result (Table 7-6) of this section to analyse the impact of proposed changes, by the use of two-dimensional matrixes.

7.3.5 Creation of Relationship Matrixes

Requirements Matrix

Table 7-7 is a relational matrix that illustrates the relationship between requirements of the cooling system. The matrix indicates the extent of impact by S-Strong, M-Medium and W-Weak. The propagation path of changes is determined by extracting all strongly impacted requirements. Similar to the first case study, propagation path generation is governed by the stop criteria in chapter 5. Therefore, the propagation path consists of the affected requirements.

Requirements versus Design Parameters Matrix

The affected requirements identified from the requirements matrix are used to identify associated design parameters, from Table 7-8. The result of this exercise is a list of affected design parameters. This list is a worst case scenario, which will require an engineer's assessment for most relevant design parameters to be considered for cost estimation.

Table 7-7: Requirements Relationship Matrix

		R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13
		FR1. The CS should allow fluid to flow from one subsystem to the other	FR2. The CS material must facilitate heat conservation	FR3. The clearance distance between the hose and other parts should not be less than 25mm	FR4. The CS must facilitate heat exchange with the environment	FR5. There should be no leakage between system component	FR7. The radiator will be free from cosmetic corrosion during the first 3 years of ownership	FR8. The CS must have a mechanism for relieving pressure	FR9. The CS must facilitate temerature elevation (cold start)	FR10. The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap	FR11. The CS must be able to control heat temperature	FR12. The CS must circulate fluid through the engine	FR13. The CS must draw outside air into the engine compartment to cool the engine	FR14. The CS must ensure that there is no internal recirculation within the cooling pack under most conditions
R1	The CS should allow fluid to flow from one subsystem to the other	0		S	W	S	S					M		
R2	The CS material must facilitate heat conservation		0	M	M	W	M		M		M	M	M	M
R3	The clearance distance between the hose and other parts should not be less than 25mm	S	M	0		M						M		
R4	The CS must facilitate heat exchange with the environment	W	M		0	W	W	S			W		S	S
R5	There should be no leakage between system component	S	W	M	W	0								
R6	The radiator will be free from cosmetic corrosion during the first 3 years of ownership	S	M		W		0		M					
R7	The CS must have a mechanism for relieving pressure				S			0		M		W		
R8	The CS must facilitate temerature elevation (cold start)		M				M		0		M	W	W	W
R9	The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap							M		0				
R10	The CS must be able to control heat temperature		M		W				M		0	M	M	M
R11	The CS must circulate fluid through the engine	M	M	W				W	W		M	0		
R12	The CS must draw outside air into the engine compartment to cool the engine		M		S				W		M		0	S
R13	The CS must ensure that there is no internal recirculation within the cooling pack under most conditions		M		S				W		M		S	0

Table 7-8: Requirements and Design Parameter Matrix

		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	DP11	DP12	DP13	DP14	DP15	DP16	DP17	DP18	DP19	DP20	DP21	DP22	DP23	DP24	DP25	DP26	DP27	DP28
		Hose-cooling system bleed (30cm)	Hose-engine coolant valve (35cm) 2 bends	Hose-engine to oil cooler coolant (40cm) 2 bends	Hose-expansion tank coolant (40cm) 2 bends	Hose-expansion tank to pump coolant (35cm)	Hose-four way connector (30cm) 3 bends	Hose-oil cooler to rail coolant (35cm)	Hose-radiator to thermostat coolant (30cm)	Bracket-oil pipe mounting	Clip - pipe	Clip-coolant hose	Clip-spring band	Pipe-oil cooler to transmission (30cm)	Pipe-transmission to oil cooler (35cm)	Clip-hose (semi std part)	Mount-radiator rubber	Bracket-radiator mounting (lh)	Bracket-radiator mounting (rh)	Condenser assy-air conditioning	Frame-cooling system	Radiator-cooling system (fins, tubes, endtanks)	Cap-expansion tank pressure	Expansion tank	Housing-thermostat	Thermostat sensor	Pump	Cowl-cooling system fan	Engine fan
R1	The CS should allow fluid to flow from one subsystem to the other	X	X	X	X	X	X	X	X					X	X														
R2	The CS material must facilitate heat conservation		X	X	X	X		X	X					X	X														
R3	The clearance distance between the hose and other parts should not be less than 25mm	X	X	X	X	X	X	X	X					X	X														
R4	The CS must facilitate heat exchange with the environment																			X	X								
R5	There should be no leakage between system component									X	X	X	X			X	X	X	X										
R6	The radiator will be free from cosmetic corrosion during the first 3 years of ownership																			X		X							
R7	The CS must have a mechanism for relieving pressure																						X						
R8	The CS must facilitate temerature elevation (cold start)																						X						
R9	The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap																							X					
R10	The CS must be able to control heat temperature																								X	X			
R11	The CS must circulate fluid through the engine																										X		
R12	The CS must draw outside air into the engine compartment to cool the engine																											X	
R13	The CS must ensure that there is no internal recirculation within the cooling pack under most conditions																												X

Table 7-9: Design Parameter Relationship Matrix

		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	DP11	DP12	DP13	DP14	DP15	DP16	DP17	DP18	DP19	DP20	DP21	DP22	DP23	DP24	DP25	DP26	DP27	DP28
		Hose-cooling system bleed (30cm)	Hose-engine coolant valve (35cm) 2 bends	Hose-engine to oil cooler coolant (40cm) 2 bends	Hose-expansion tank coolant (40cm) 2 bends	Hose-expansion tank to pump coolant (35cm)	Hose-four way connector (30cm) 3 bends	Hose-oil cooler to rail coolant (35cm)	Hose-radiator to thermostat coolant (30cm)	Bracket-oil pipe mounting	Clip - pipe	Clip-coolant hose	Clip-spring band	Pipe-oil cooler to transmission (30cm)	Pipe-transmission to oil cooler (35cm)	Clip-hose (semi std part)	Mount-radiator rubber	Bracket-radiator mounting (lh)	Bracket-radiator mounting (rh)	Condenser assy-air conditioning	Frame-cooling system	Radiator-cooling system (fins, tubes, endtanks)	Cap-expansion tank pressure	Expansion tank	Housing-thermostat	Thermostat sensor	Pump	Cowl-cooling system fan	Engine fan
DP1	Hose-cooling system bleed (30cm)	0	X	X	X	X	X	X	X					X	X							X					X		
DP2	Hose-engine coolant valve (35cm) 2 bends	X	0	X	X	X	X	X	X					X	X							X					X		
DP3	Hose-engine to oil cooler coolant (40cm)	X	X	0	X	X	X	X	X					X	X							X					X		
DP4	Hose-expansion tank coolant (40cm) 2 bends	X	X	X	0	X	X	X	X					X	X							X					X		
DP5	Hose-expansion tank to pump coolant (35cm)	X	X	X	X	0	X	X	X					X	X							X					X		
DP6	Hose-four way connector (30cm) 3 bends	X	X	X	X	X	0	X	X					X	X							X					X		
DP7	Hose-oil cooler to rail coolant (35cm)	X	X	X	X	X	X	0	X					X	X							X					X		
DP8	Hose-radiator to thermostat coolant (30cm)	X	X	X	X	X	X	X	0					X	X							X					X		
DP9	Bracket-oil pipe mounting									0				X	X							X							
DP10	Clip - pipe										0			X	X							X							
DP11	Clip-coolant hose											0		X	X							X							
DP12	Clip-spring band												0	X	X							X							
DP13	Pipe-oil cooler to transmission (30cm)	X	X	X	X	X	X	X	X	X	X	X	X	0	X							X					X		
DP14	Pipe-transmission to oil cooler (35cm)	X	X	X	X	X	X	X	X	X	X	X	X	X	0							X					X		
DP15	Clip-hose (semi std part)															0						X							
DP16	Mount-radiator rubber																0					X							
DP17	Bracket-radiator mounting (lh)																	0				X							
DP18	Bracket-radiator mounting (rh)																		0			X							
DP19	Condenser assy-air conditioning																			0									
DP20	Frame-cooling system																				0	X							
DP21	Radiator-cooling system (fins, tubes, endtanks)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	0							
DP22	Cap-expansion tank pressure																						0	X					
DP23	Expansion tank																						X	0	X	X			
DP24	Housing-thermostat																							X	0	X			
DP25	Thermostat sensor																							X	X	0			
DP26	Pump	X	X	X	X	X	X	X	X					X	X												0		
DP27	Cowl-cooling system fan																											0	X
DP28	Engine fan																											X	0

Design Parameter Matrix

Table 7-9 illustrates a third type of relational matrix used for constraints changing on design parameter. Table 7-9 is a square matrix that indicates the extent of impact (similar to the requirements matrix Table 7-7) by S-Strong, M-Medium and W-Weak. However, the use of this matrix does not require the stop criteria, as only one level of propagation is sufficient. The list of affected design parameter presents a worst case scenario which will also require an engineer to select most relevant design parameters for cost estimation. The next section describes how cost and time rules are created for the estimation of possible incurred cost and delay in time.

7.3.6 Cost Estimation and Time Estimation Rules

Cost estimation and time estimation rules were created in collaboration between the researcher and an OEM Project estimator, with 2 yeas experience in the automotive industry. The rules were created in 1 day, 7 hours in total. Similar to the first case study, a relational matrix for the business drivers and the components of the cooling system was created Table 7-10. The 'X's in the table illustrates the number of rules required, 3 rules for raw materials, 3 rules for tooling, 3 rules for labour, 3 rules for machinery and 1 rule for bought out items.

Table 7-10: Relational Matrix of Business Drivers and Cooling System Components

	Metal	Rubber	Plastic	Others
Raw Materials	X	X	X	
Tooling	X	X	X	
Labour	X	X	X	
Machinery	X	X	X	
Bought Out Items				X

Table 7-10 shows that plastic items are usually bought-out items. Hoses (and pipes) and radiator are considered for this exercise, the water tank is usually manufactured when a clear understanding of the relationships between the other subsystems in the cooling system is attained. The thermostat, water pump and the fan are bought-out items.

```
If the part is radiator/condenser
        Number of fins 50
        Number of tubes 10
        Aluminium sheet area (50*10) = 500
        Cost of aluminium per cm² is 0.02
                Then cost is (500*0.02) = €10.00

Else if the part is pipe
        Length of pipe 30cm
        Radius of pipe 2cm
        Metal sheet area (30*2) = 60
        Cost of metal per cm² is 0.10
                Then cost is (60*0.10) = €6.00

Else if the part is frame
                Then cost is €1.5
```

Figure 7-7: Rule 1 - Raw material cost for metal

Figure 7-7 is an example of cooling system rule. Similar to the seat system rules, the cooling system rules were created by the researcher, an OEM cooling system cost estimator and a Tier 2 Supplier project estimator. Figure 7-7 shows the factor governing the creation of the raw material rule. The type of part, the number of fins, the number of tubes, cost of aluminium, length of pipe, radius of pipe and cost of pipe metal are the main inputs for the radiator/condenser raw material and metal pipes; the metal area is calculated and divided by the total number of fins. The researcher asked the OEM cooling system project estimator and a Tier 2 Supplier project estimator for the rationale behind the value generated for the cost. The researcher was told that the exact figures and formula cannot be divulged since competitors will have an insight into how their cost estimation is done. The project estimator included multipliers in some of the rules in a bid to hide the exact formula used to calculate incurred cost.

The project estimator mentioned that an additional tooling cost is incurred for every bend on the hoses, as illustrated in Figure 7-8. This special case applies to rule 6, were mandrels are required. A mandrel here is a metal bar around which the soft hose is bent and left to thicken, in order to take a required shape. The length of hoses play an important role in the cost of raw materials required as illustrated in Figure 7-7 (rule 1), the length is usually measured in centimetres.

Figure 7-8: Hose-engine to oil coolant with 2 bends (DP3) (Courtesy of Visteon LTD).

For example, the hose that connects the engine to the oil coolant (DP3) is 40cm; the hoses have an average radius of 2cm, total raw material required is 40 multiplied by 2, which equal 80. Cost of metal per cm squared is €0.05. Therefore, the incurred cost is €3, as illustrated in Figure 7-9.

If the part is hose
    Length of hose 30cm
    Radius of hose 2cm
    Volume 30*2 = 60
    Cost of metal per cm^2 is €0.05
        Then cost is (60*0.05) = **€3.00**

Figure 7-9: Rule 2 – Raw material cost for rubber

The rest of the rules in Appendix F were created in a similar way to that of the raw material cost for metal. The cost shown in the rules are the incurred cost when a requirement change affects the cost drivers. Similar to the cost rules, time rules are created to illustrate incurred delay in time when requirement change is proposed, Appendix F.

7.4 Application of CIAM on the Cooling System

7.4.1 Example of Changes to the Cooling System

Similar to the seat system, the cooling system exhibits requirement changes; these changes can be constraints changing on requirements or constraints changing on design parameters.

Table 7-11: Examples of Changes to the Cooling System

	Changes	**Systems/subsystems affected**	**Type of change**
1	Reduction (or increase) in the number of hoses.	Hoses	DP
2	Reduction (or increase) in the length of the fins in the radiator.	Hoses	DP
3	Hose clashing. The hoses must not be less than 25 millimetres apart. In these cases, the hoses may need to have multiple bends, which can in turn require new mandrels.	Hoses, engine	DP
4	Clips failure, situation arises where the current hose clips are not adequate for the hoses and new ones are purchased to meet the current requirements	Hoses, radiator	DP
5	Engine change may lead to increase or reduction of heat exchange area. It may also lead to change in water pump requirement	Engine, radiator	R
6	Improve quality of radiator, it is not adequate for the intended car (mainly due to cracking, splitting, etc)	Radiator	R
7	Improve quality of hoses, they are not adequate for the intended car (mainly due to cracking, splitting, etc)	Hoses	R

A list of sample changes to the cooling system was elicited during an interview session Table 7-11 A Cost Engineer and a Design Engineer were interviewed, they were asked to describe examples of what is frequently changed in the cooling system.

Hose clashing. The hoses must not be less than 25 millimetres apart. In these cases, the hoses may need to have multiple bends, which can in turn require new mandrels. Clips failure is another situation that arises when the current hose clips are not adequate for the hoses. In these cases, new clips are purchased to meet the new requirements. Quality issues and cracking issues can also lead to proposition of requirement changes. Cost reduction and deletion is another reason for requirement changes. During cost reduction exercises, sometimes items are removed or cheaper materials are sorted after. For example, the number of hoses and the length of the fins in the radiator can be reduced to save cost. Similar to the seat system there are two types of changes: constraints changing on requirements and constraints changing on design parameters.

7.4.2 Scenario 1: Constraint Changing on Requirements

For example, a requirement change is proposed due to a change to engine overheat i.e.

INPUT:

The engine needs to be cooled faster.

- This is due to the vehicle engine over heating
- Making the hoses shorter will cool the engine faster, since fluid will flow faster.

Business Driver Parameters

- New raw material is required since hoses are not reusable
- There is a unit charge for the use of the mandrels
- There is a unit charge for the use of the extruder

During the data collect period of the cooling system case study, the interviewees mentioned that a major issue with the cooling system is a change request to speed up the cooling capability of the cooling system. This change is related to R1 “The CS should allow fluid to flow from one subsystem to the other”. The propagation path for a change to R1 is shown in Table 7-12, this is determined by listing the strongly impacted requirements in Table 7-7.

Table 7-12: Requirements Affected by Changing R1 – The CS should allow fluid to flow from one subsystem to the other

R1	The CS should allow fluid to flow from one subsystem to the other
R3	The clearance distance between the hose and other parts should not be less than 25mm
R5	There should be no leakage between system component
R6	The radiator will be free from cosmetic corrosion during the first 3 years of ownership

Table 7-13: Design Parameters Associated to R1

		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP9	DP10	DP11	DP12	DP13	DP14	DP15	DP16	DP17	DP18	DP19	DP21
		Hose-cooling system bleed (30cm)	Hose-engine coolant valve (35cm) 2 bends	Hose-engine to oil cooler coolant (40cm) 2 bends	Hose-expansion tank coolant (40cm) 2 bends	Hose-expansion tank to pump coolant (35cm)	Hose-four way connector (30cm) 3 bends	Hose-oil cooler to rail coolant (35cm)	Hose-radiator to thermostat coolant (30cm)	Bracket-oil pipe mounting	Clip - pipe	Clip-coolant hose	Clip-spring band	Pipe-oil cooler to transmission (30cm)	Pipe-transmission to oil cooler (35cm)	Clip-hose (semi std part)	Mount-radiator rubber	Bracket-radiator mounting (lh)	Bracket-radiator mounting (rh)	Condenser assy-air conditioning	Radiator-cooling system (fins, tubes, endtanks)
R1	The CS should allow fluid to flow from one subsystem to the other	X	X	X	X	X	X	X	X					X	X						
R3	The clearance distance between the hose and other parts should not be less than 25mm	X	X	X	X	X	X	X	X					X	X						
R5	There should be no leakage between system component									X	X	X	X			X	X	X	X		
R6	The radiator will be free from cosmetic corrosion during the first 3 years of ownership																			X	X

Table 7-14: Worst-Case List of Affected Design Parameters

DP1	Hose-cooling system bleed (30cm)	
DP2	Hose-engine coolant valve (35cm) 2 bends	
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends	
DP4	Hose-expansion tank coolant (40cm) 2 bends	
DP5	Hose-expansion tank to pump coolant (35cm)	
DP6	Hose-four way connector (30cm) 3 bends	
DP7	Hose-oil cooler to rail coolant (35cm)	
DP8	Hose-radiator to thermostat coolant (30cm)	
DP9	Bracket-oil pipe mounting	
DP10	Clip - pipe	
DP11	Clip-coolant hose	X
DP12	Clip-spring band	
DP13	Pipe-oil cooler to transmission (30cm)	X
DP14	Pipe-transmission to oil cooler (35cm)	X
DP15	Clip-hose (semi std part)	
DP16	Mount-radiator rubber	
DP17	Bracket-radiator mounting (lh)	
DP18	Bracket-radiator mounting (rh)	
DP19	Condenser assy-air conditioning	X
DP21	Radiator-cooling system (fins, tubes, end tanks)	

Table 7-15: Subset of DPs Related to R1

DP1	Hose-cooling system bleed (30cm)
DP2	Hose-engine coolant valve (35cm) 2 bends
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends
DP4	Hose-expansion tank coolant (40cm) 2 bends
DP5	Hose-expansion tank to pump coolant (35cm)
DP6	Hose-four way connector (30cm) 3 bends
DP7	Hose-oil cooler to rail coolant (35cm)
DP8	Hose-radiator to thermostat coolant (30cm)
DP9	Bracket-oil pipe mounting
DP10	Clip - pipe
DP12	Clip-spring band
DP15	Clip-hose (semi std part)
DP16	Mount-radiator rubber
DP17	Bracket-radiator mounting (lh)
DP18	Bracket-radiator mounting (rh)
DP21	Radiator-cooling system (fins, tubes, end tanks)

Table 7-16: Cost Impact Analysis Summary

		Cost											Time					
	Affected DPs	**Old Cost**		**Raw Material**	**Tooling**	**Machinery**	**Labour**	**Bought Out**		**Delta Cost**	**% inc**		**Raw Material**	**Tooling**	**Labour**	**Machinery**	**Bought Out**	**External Impacts**
DP1	Hose-cooling system bleed (30cm)	€ 6.00		€ 3.00	€ 0.50	€ 1.20	€ 0.60			€ 5.30	88.33		1 week	1 week	1 week	1 week		Engine
DP2	Hose-engine coolant valve (35cm) 2 bends	€ 6.00		€ 3.50	€ 0.10	€ 1.20	€ 0.60			€ 5.40	90.00		1 week	1 week	1 week	1 week		Engine
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends	€ 7.00		€ 4.00	€ 0.10	€ 1.20	€ 0.60			€ 5.90	84.29		1 week	1 week	1 week	1 week		Engine
DP4	Hose-expansion tank coolant (40cm) 2 bends	€ 7.00		€ 4.00	€ 0.10	€ 1.20	€ 0.60			€ 5.90	84.29		1 week	1 week	1 week	1 week		Engine
DP5	Hose-expansion tank to pump coolant (35cm)	€ 7.00		€ 3.50	€ 0.50	€ 1.20	€ 0.60			€ 5.80	82.86		1 week	1 week	1 week	1 week		Engine
DP6	Hose-four way connector (30cm) 3 bends	€ 7.00		€ 3.00	€ 1.50	€ 1.20	€ 0.60			€ 6.30	90.00		1 week	1 week	1 week	1 week		Engine
DP7	Hose-oil cooler to rail coolant (35cm)	€ 8.00		€ 3.50	€ 1.50	€ 1.20	€ 0.60			€ 6.80	85.00		1 week	1 week	1 week	1 week		Engine
DP8	Hose-radiator to thermostat coolant (30cm)	€ 7.00		€ 3.00	€ 1.50	€ 1.20	€ 0.60			€ 6.30	90.00		1 week	1 week	1 week	1 week		Engine
DP9	Bracket-oil pipe mounting	€ 2.00						€ 2.00		€ 2.00	100.00						2 weeks	
DP10	Clip - pipe	€ 2.00						€ 2.00		€ 2.00	100.00						2 weeks	
DP12	Clip-spring band	€ 2.00						€ 2.00		€ 2.00	100.00						2 weeks	
DP15	Clip-hose (semi std part)	€ 2.00						€ 2.00		€ 2.00	100.00						2 weeks	
DP16	Mount-radiator rubber	€ 1.50						€ 1.50		€ 1.50	100.00						2 weeks	Grill, bumper, engine
DP17	Bracket-radiator mounting (lh)	€ 2.00						€ 2.00		€ 2.00	100.00						2 weeks	Grill, bumper, engine
DP18	Bracket-radiator mounting (rh)	€ 2.00						€ 2.00		€ 2.00	100.00						2 weeks	Grill, bumper, engine
DP21	Radiator-cooling system (fins, tubes, endtanks)	€ 40.00		€ 10.00	€ 8.00	€ 2.40	€ 15.00			€ 35.40	88.50		2 weeks	2 weeks	1 week	2 weeks		Grill, bumper, engine
	TOTAL	€ 108.50		€ 37.50	€ 13.80	€ 12.00	€ 19.80	€ 13.50		€ 96.60	89.03		2 weeks	2 weeks	1 week	2 weeks	2 weeks	

The next step is to determine the associated design parameters from Table 7-8, the result is a worst case list of affected design parameters Table 7-13 and Table 7-14. Worst case scenario refers to all DPs that can be potentially affected by the change. An engineer extracts a subset of the worst-case list to derive most likely design parameters to be considered for cost impact Table 7-15.

Table 7-16 presents a cost impact analysis summary of affected design parameters. The rules in Appendix F are used to determine the incurred cost and delay in time in relation to the business drivers.

7.4.3 Business Driver Distribution Graph

In Figure 7-10 and Figure 7-11 labour will incur more cost than all other cost drivers, 42% of total incurred cost. This means that a change that affects requirement R1 in Table 7-7 is labour intensive. Raw material attracts a relatively high cost 28% of total incurred cost.

Figure 7-12 Figure 7-13 illustrates that 4 of the business drivers; bought out items, raw material, machinery and tooling will incur more delay when a change that affects the requirement "The CS should allow fluid to flow from one subsystem to the other (R1)". Although the maximum delay is not more than 2 week as illustrates in Table 7-16.

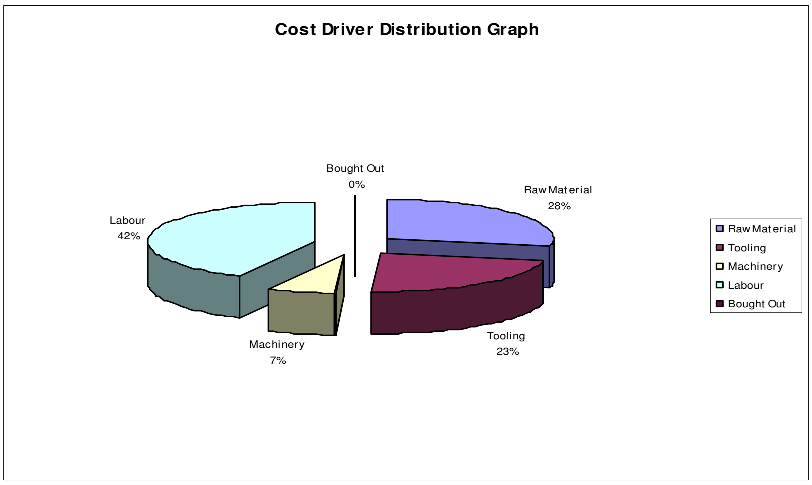


Figure 7-10: Cost Driver Distribution Pie Chart

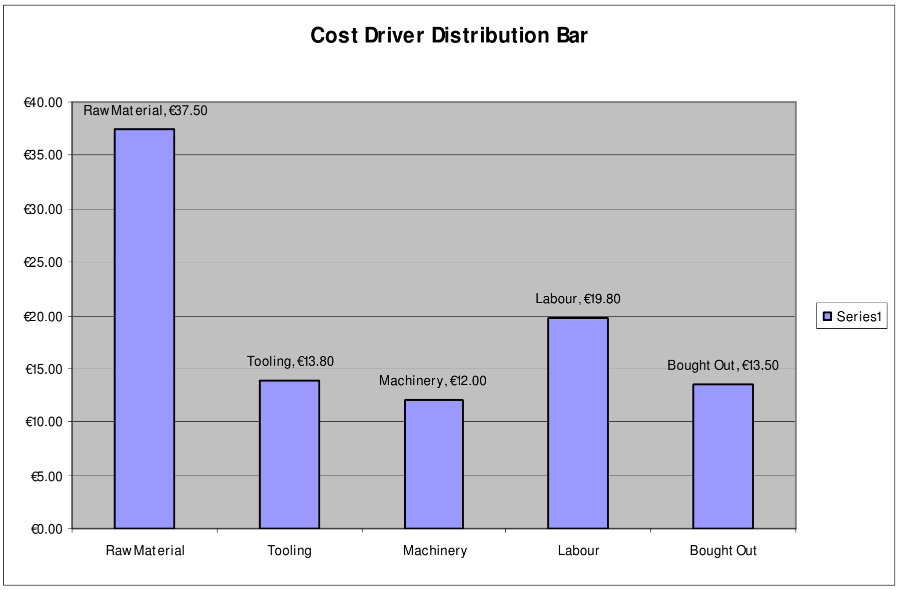


Figure 7-11: Cost Driver Distribution Bar Chart

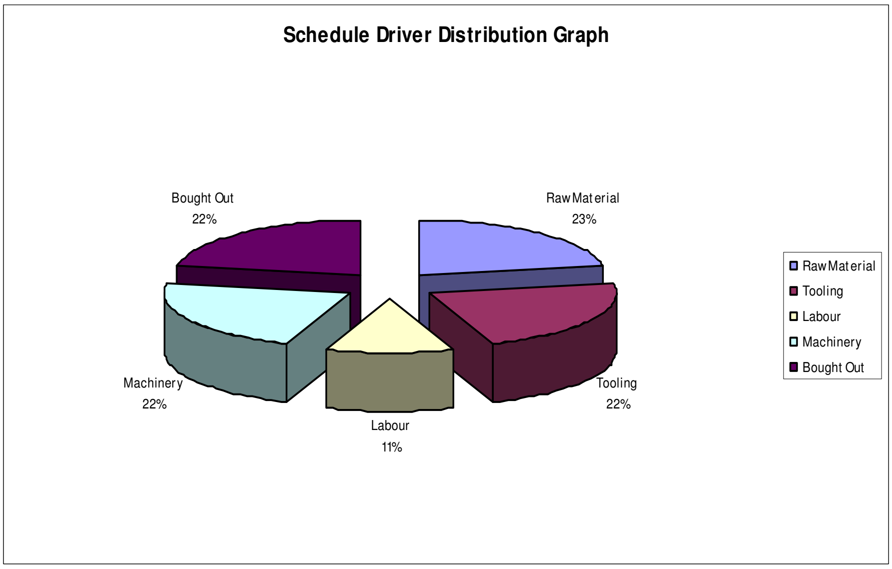


Figure 7-12: Time Driver Distribution Pie Chart

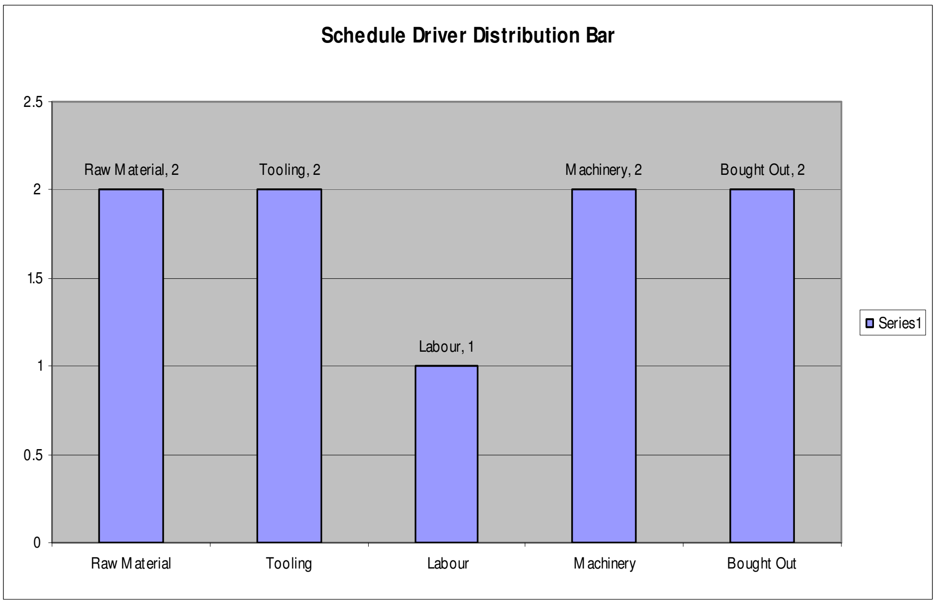


Figure 7-13: Time Cost Driver Distribution Bar Chart

External Cost Impact Analysis for Constraints Changing on Requirements

Appendix F is used to determine the external impact of a proposed change that affected R1 "The CS should allow fluid to flow from one subsystem to the other". The first step is to determine the origin of the change, in this case the hoses and the radiator. From Table 7-6, the following external (to cooling system) systems are impacted by a change to all requirements in the propagation path:

Engine
Grill, and
Bumper

As illustrated in the rules:

- A change originating from the hose that affect the engine will cost €40.00
- A change originating from the radiator that affects the engine will cost €125.00
- A change originating from the radiator that affects the grill will cost €50.00
- A change originating from the radiator that affects the bumper will cost €65.00

The cumulative cost for external impact can potentially be the sum of €40.00, €125.00, €50.00 and €65.00. The result is €280.00; this result is for the worst-case scenario. This external cost impact analysis aims to provide a high-level view of potential impact when a change is made.

7.4.4 Scenario 2: Constraint Changing on Design Parameters

As demonstrated in Chapter 6, constraints changing on design parameters are those changes that affect design parameters directly. For example, a design parameter change is proposed due to hose clashing,

INPUT:

Hose clashing

- That is hose rubbing against each other, this can cause damage to the hoses

Business Driver Parameters

- Driver options are beside each DP

This change is related to DP1, DP2, DP3, DP4, DP5, DP6, DP7, DP8 and DP15. Table 7-9 is used to generate all other DPs that can be potentially affected by a change that affects hoses, Table 7-17. These are referred to as a worst case list of affected design parameters.

Table 7-17: Design Parameters Related to Hose Clashing

		DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8	DP13	DP14	DP21	DP26
		Hose-cooling system bleed (30cm)	Hose-engine coolant valve (35cm) 2 bends	Hose-engine to oil cooler coolant (40cm) 2 bends	Hose-expansion tank coolant (40cm) 2 bends	Hose-expansion tank to pump coolant (35cm)	Hose-four way connector (30cm) 3 bends	Hose-oil cooler to rail coolant (35cm)	Hose-radiator to thermostat coolant (30cm)	Pipe-oil cooler to transmission (30cm)	Pipe-transmission to oil cooler (35cm)	Radiator-cooling system (fins, tubes, end tanks)	Pump
DP1	Hose-cooling system bleed (30cm)	0	X	X	X	X	X	X	X	X	X	X	X
DP2	Hose-engine coolant valve (35cm) 2 bends	X	0	X	X	X	X	X	X	X	X	X	X
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends	X	X	0	X	X	X	X	X	X	X	X	X
DP4	Hose-expansion tank coolant (40cm) 2 bends	X	X	X	0	X	X	X	X	X	X	X	X
DP5	Hose-expansion tank to pump coolant (35cm)	X	X	X	X	0	X	X	X	X	X	X	X
DP6	Hose-four way connector (30cm) 3 bends	X	X	X	X	X	0	X	X	X	X	X	X
DP7	Hose-oil cooler to rail coolant (35cm)	X	X	X	X	X	X	0	X	X	X	X	X
DP8	Hose-radiator to thermostat coolant (30cm)	X	X	X	X	X	X	X	0	X	X	X	X
DP15	Clip-hose (semi std part)											X	

Table 7-18: Worst-Case List of DPs Related to Clashing in Hoses

DP1	Hose-cooling system bleed (30cm)	
DP2	Hose-engine coolant valve (35cm) 2 bends	
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends	
DP4	Hose-expansion tank coolant (40cm) 2 bends	
DP5	Hose-expansion tank to pump coolant (35cm)	
DP6	Hose-four way connector (30cm) 3 bends	
DP7	Hose-oil cooler to rail coolant (35cm)	
DP8	Hose-radiator to thermostat coolant (30cm)	
DP13	Pipe-oil cooler to transmission	x
DP14	Pipe-transmission to oil cooler	X
DP15	Clip-hose (semi std part)	X
DP21	Radiator-cooling system (fins, tubes, end tanks)	X
DP26	Pump	X

A design engineer now selects a subset from the worst case list in Table 7-18, the purpose of this task is to select the most relevant design parameters for cost analysis Table 7-19. Similar to the seat case study and scenario 1 of the cooling system, the incurred cost is determined by identifying values from the cost and time rules in Appendix F. For example, Rule 1, if the part to be changed is a radiator the potential cost of the change, with regards to the raw material cost driver is €10.00. The rules are use in a similar fashion to identify the incurred cost on each cost driver and time driver for each item in the list of affected design parameters Table 7-20.

Table 7-19: Subset of DP Related to Clashing in Hoses

DP1	Hose-cooling system bleed (30cm)
DP2	Hose-engine coolant valve (35cm) 2 bends
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends
DP4	Hose-expansion tank coolant (40cm) 2 bends
DP5	Hose-expansion tank to pump coolant (35cm)
DP6	Hose-four way connector (30cm) 3 bends
DP7	Hose-oil cooler to rail coolant (35cm)
DP8	Hose-radiator to thermostat coolant (30cm)

Table 7-20: Cost Impact Analysis Summary for Changes Related to Hoses Clashing

		Cost											Time					
	Affected DPs	Old Cost		Raw Material	Tooling	Labour	Machinery	Bought Out		Delta Cost	% inc		Raw Material	Tooling	Labour	Machinery	Bought out	External Impacts
DP1	Hose-cooling system bleed (30cm)	€ 20.00		€ 3.00	€ 0.50	€ 0.60	€ 1.20			€ 5.30	26.50		1 week	1 week	1 week	1 week		Engine
DP2	Hose-engine coolant valve (35cm) 2 bends	€ 20.00		€ 3.50	€ 0.10	€ 0.60	€ 1.20			€ 5.40	27.00		1 week	1 week	1 week	1 week		Engine
DP3	Hose-engine to oil cooler coolant (40cm) 2 bends	€ 20.00		€ 4.00	€ 1.00	€ 0.60	€ 1.20			€ 6.80	34.00		1 week	1 week	1 week	1 week		Engine
DP4	Hose-expansion tank coolant (40cm) 2 bends	€ 20.00		€ 4.00	€ 0.10	€ 0.60	€ 1.20			€ 5.90	29.50		1 week	1 week	1 week	1 week		Engine
DP5	Hose-expansion tank to pump coolant (35cm)	€ 20.00		€ 3.50	€ 0.50	€ 0.60	€ 1.20			€ 5.80	29.00		1 week	1 week	1 week	1 week		Engine
DP6	Hose-four way connector (30cm) 3 bends	€ 20.00		€ 3.00	€ 1.50	€ 0.60	€ 1.20			€ 6.30	31.50		1 week	1 week	1 week	1 week		Engine
DP7	Hose-oil cooler to rail coolant (35cm)	€ 20.00		€ 3.50	€ 1.50	€ 0.60	€ 1.20			€ 6.80	34.00		1 week	1 week	1 week	1 week		Engine
DP8	Hose-radiator to thermostat coolant (30cm)	€ 20.00		€ 3.00	€ 1.50	€ 0.60	€ 1.20			€ 6.30	31.50		1 week	1 week	1 week	1 week		Engine
	TOTAL	€ 160.00		€ 27.50	€ 6.70	€ 4.80	€ 9.60	€ 0.00		€ 48.60	30.38		1 week	1 week	1 week	1 week		

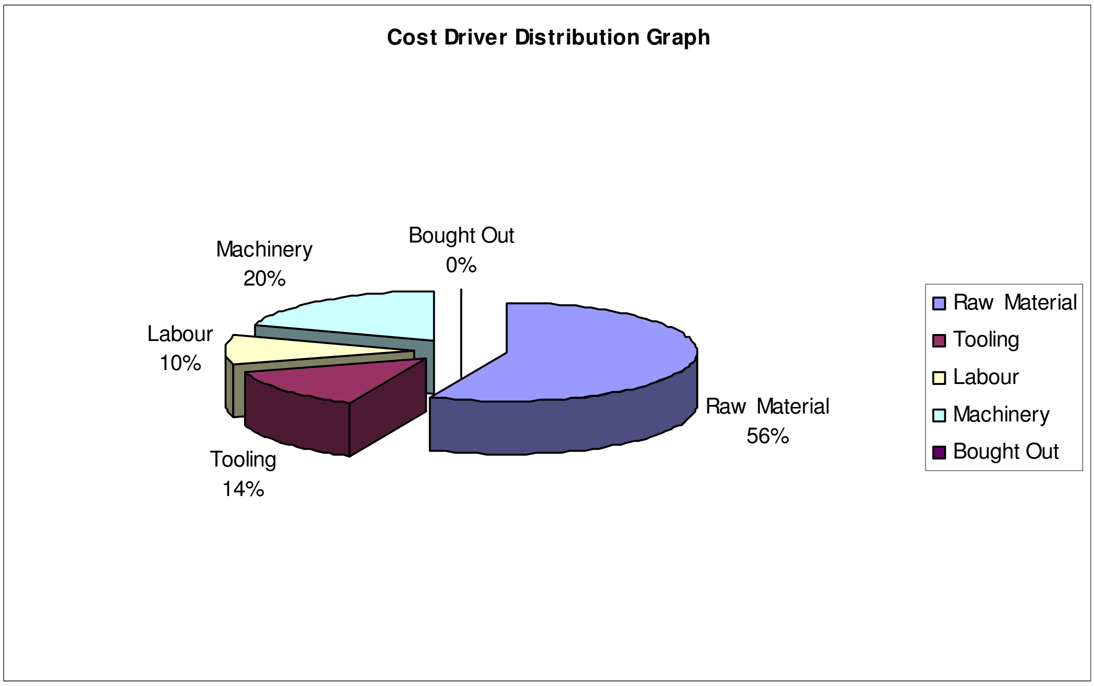


Figure 7-14: Cost Driver Distribution Pie Chart

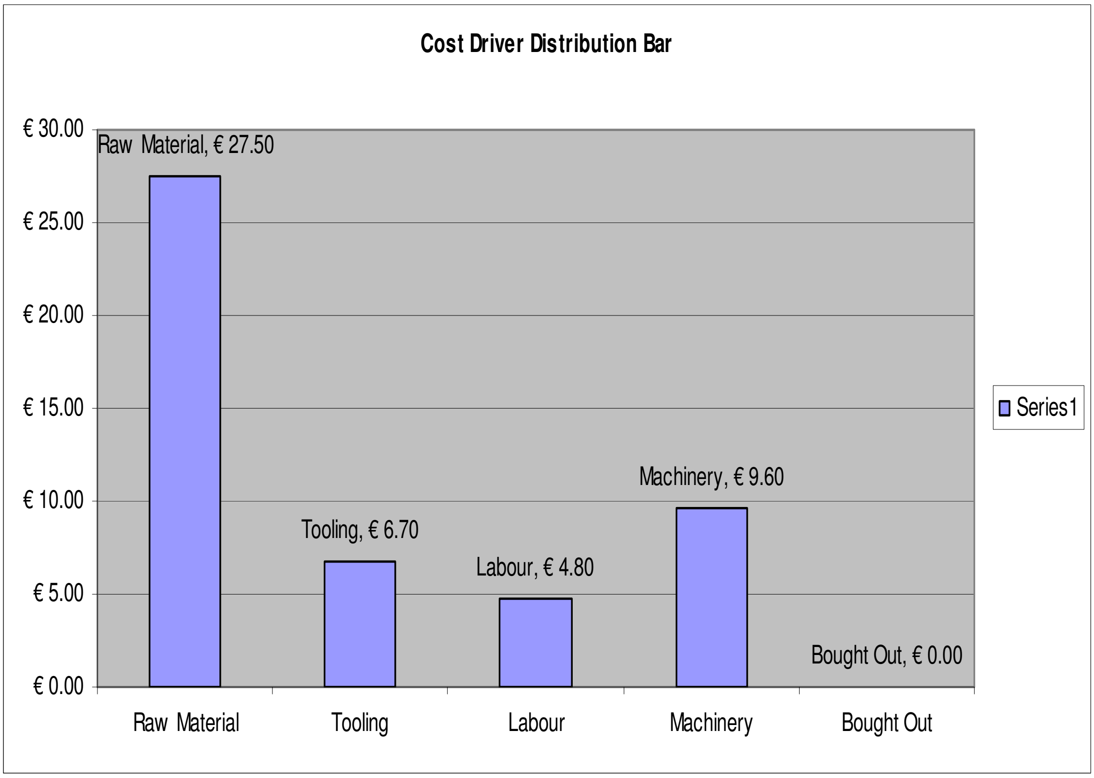


Figure 7-15: Cost Driver Distribution Bar Chart

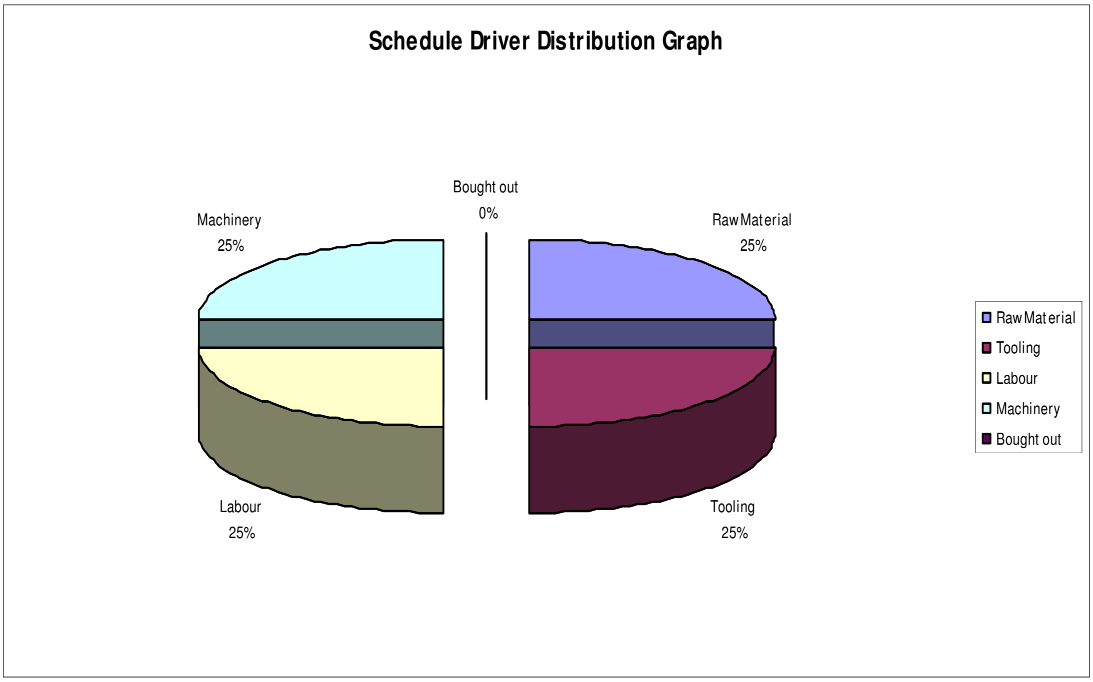


Figure 7-16: Time Driver Distribution Pie Chart

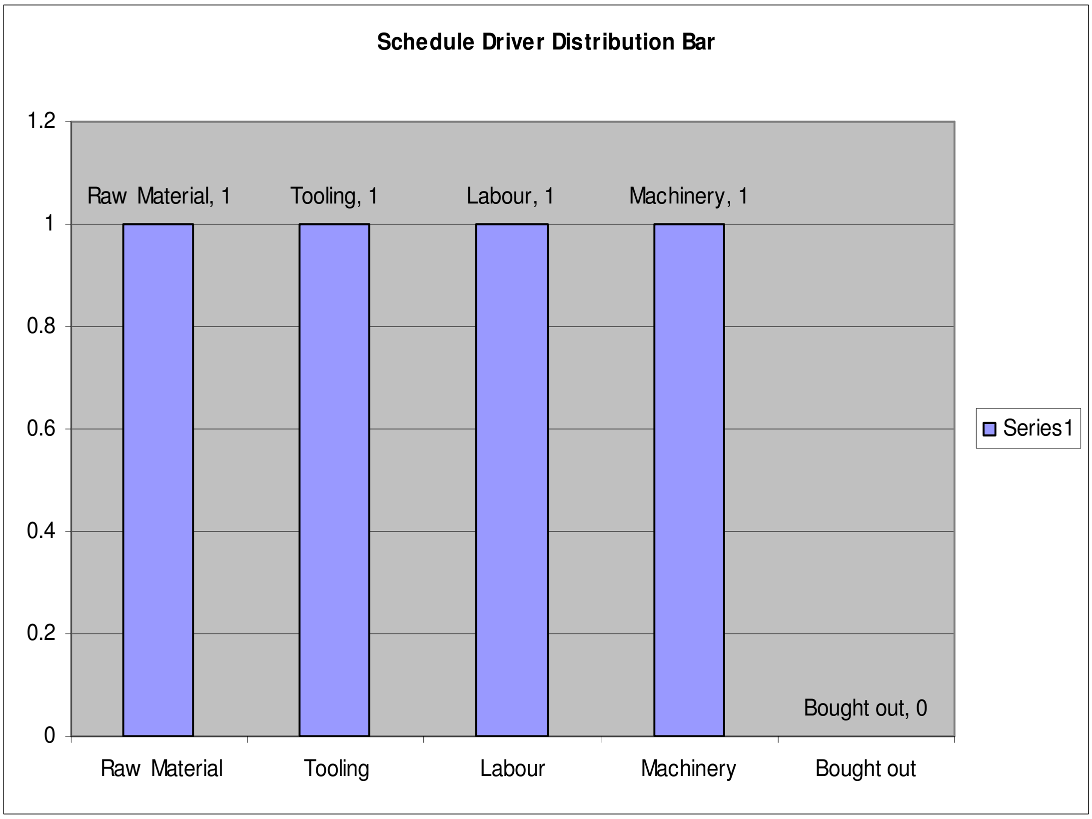


Figure 7-17: Time Driver Distribution Bar Chart

7.4.5 Business Driver Distribution Graph

Figure 7-14 and Figure 7-15 illustrates that raw materials will incur more cost 56% of total incurred cost, than all other cost drivers. This means that changes that affect hoses incur high raw materials cost. Machinery cost is relatively high as well 20%.

Since all the affected DPs have 1 week time for all business drivers as depicted in Figure 7-16 and Figure 7-17, the maximum delay in time when a change affects the hose is 1 week.

External Cost Impact Analysis for Constraints Changing on Design Parameters

Similar to the external cost impact analysis for constraints changing on requirements, this section determines the external impact of a proposed change due to hose clashing. The first step is to determine the origin of the change, in this case the hose. From Table 7-6, the following external (to cooling system) system is affected by a change originating from the hose:

- Engine

As illustrated in the rules:

- A change originating from the hose that affect the engine will cost €40.00

The cumulative cost for external impact can potentially be €40.00; again this result is for the worst-case scenario, as explained in section 5.5. This external cost impact analysis aims to provide a high-level view of potential impact when a change is made.

7.5 Validation of Cooling System Case Study

A validation workshop was held at the OEM organisation, involving the researcher and 3 experts from the automotive industry, as shown in Table 7-21. There were 2 sessions which lasted for a whole day. The two scenarios in section 7.7.2 and section 7.7.4 were used as raw data for the validation workshop. Prior to the validation workshop the researcher was always in constant communication with the 3 experts, so the experts had a very good understanding of the work carried out.

Table 7-21: List of Cooling System Case Study Validation Participants

Job Title	Organisation	Years of Experience
Design Engineer	OEM	4
Project Estimator	OEM	2
Accounts Manager	Tier 1 Supplier	4

7.5.1 The First Session

The first session was between the researcher, the Design Engineer and the Project Estimator in Table 7-21. The focus of the session was on the extraction methodology and the population of matrixes. The experts checked the identified subsystems in Table 7-1 and agreed that the table represents a true reflection of the subsystem of a typically cooling system. The identified business drivers in Table 7-4 were validated and it was agreed that raw materials, tooling, labour, machinery and bought out items should be used for the case study demonstration. The relevant data repository in Table 7-6 was also checked for consistency; initially the author did not include the length and number of bends on the hoses. The project estimator mentioned that it will be necessary to know the length and number of bends in order to estimate incurred cost of changes that affects the hoses. Finally the populated matrixes were check and corrected, as the researcher had established relationship between non related entries in Table 7-7, Table 7-8 and Table 7-9.

7.5.2 The Second Session

The second session was between the researcher, the Project Estimator and the Accounts Manager in Table 7-21. The focus of this session was on the application of the cost and time estimation rules. The rules were also checked for consistency by both experts for consistency. The rules were used to populate Table 7-16 and Table 7-20 for constraints changing on requirements and constraints changing on design parameters. The external cost impact analysis rules was also validated, the experts argued that is was necessary to have the rule divided into 4 parts each related to a subsystem of the cooling system.

Expert Comments:

- The main benefit of the case studies was a better understanding of what other components and system are affected by what is supposed to be a simple change.
- The use of design parameter matrix to determine the cost impact of constraints changing on design parameter looks cumbersome. However, the potential benefits outweigh the efforts required.
- The 3 experts involved in the validation of the cooling system Table 7-21, further confirmed that the REXTRAM and CIAM offered a way of keeping records of past changes for future reference.

7.6 Independent Expert Validation

A further workshop was held, to provide independent validation of the seat case study analysis and the cooling system case study analysis. The independent expert has 30 years experience in the automotive industry; he had worked on different systems including seating and cooling systems. The validation process was a step-by-step paper based simulation. The validation process took two days, seven hours each day. The validation was divided into three stages.

7.6.1 First Stage:

The first half of the first day (about three hours thirty minutes) began with the introduction of the terminologies used in this research. The research concept "Cost Impact Analysis Methodology", the research function "Design Requirements Change Management" and the research context/domain "Mechanical Design Components within the Automotive Industry" was explained. This provided the expert with a clear picture of the research area.

This was done with the aid of PowerPoint presentation slides; the content of the slides is as follows:

- Brief introduction
- Research concept, research function and research context/domain
- Internal impact analysis
- External impact analysis
- Requirements
- Design Parameters
- Cost Drivers
- REXTRAM
- CIAM
- Matrix

7.6.2 Second Stage:

The second half of the first day (about three hours thirty minutes) was spent explaining the CIAM flowchart and REXTRAM flowchart to the expert. The expert was also provided with a detail description of how the two methodologies were developed. This was done via PowerPoint presentation slides. At the end of this session the expert had a clear picture of what the methodologies do.

7.6.3 Third Stage:

The second day was spent presenting PowerPoint slides to simulate both constraints changing on requirements and constraints changing on design parameters. The content of the presentation slides was the same as the analysis provided in chapter 5, chapter 6 and chapter 7. At each stage the expert's comments were noted.

Expert Comments:

- The methodologies will provide cost estimators and design engineers with a tool to start change negotiations and opportunity to see the potential impact of a proposed change before resources are committed to the change.
- The methodology will be good for highlighting the complexity of the domain and establishing relationship between requirements, design parameters and cost rules.
- The use of design parameter matrix to determine the cost impact of constraints changing on design parameter looks cumbersome. However, the potential benefits outweigh the efforts required.
- The methodology did not cover issues such as warranty and product recall issues. To this comment the researcher espoused that warranty and product recall issues are outside the scope of the research
- The expert also suggested that a graph comparing the cost drivers would of benefit to project managers, as it will provide a visual representation of the cost distribution. The research included the graphs at the end of each scenario for each of the case studies.

7.7 Key Observations

The objective of this case study was to investigate the application of REXTRAM and CIAM on another case study. The author wanted to see if the methodologies will be applicable to other automotive systems.

- All experts involved agreed that the interaction and understanding between requirements and design parameters was improved due to REXTRAM and CIAM.
- Because the methodology involved both design engineers and cost estimators, the experts commented in a positive way about the 'knowledge exchange' that occurred during the meetings between the two groups.
- All the participants agreed that the methodologies are applicable to most mechanical component within the automotive industry.
- The main limitation to these methodologies would be the time required to analysis design documents and the time required to populate the three types of matrixes.

7.8 Summary

In this chapter the author presented a second case study using the extraction methodology in chapter 5 and the cost impact analysis methodology in chapter 6. The seat case showed that cost estimation of requirement changes can be structured; this chapter further validates this assumption with the cooling system case study. The case study was deemed a success, since the design engineers were able to generate ripple effect propagation path for proposed changes, and the cost estimator were able to determine incurred cost of a proposed change. The result were validated and accepted by all participants of the case study.

The author also conducted an independent expert validation of both case studies. Again the results were encouraging, as the expert (a well versed veteran of the automotive industry) commented that CIAM would be of benefit to both experienced cost estimators and design engineers alike. In the next chapter a detailed analysis and design of CIAM is presented for prototype development.

8 IMPLEMENTATION OF CIAM

8.1 Introduction

This chapter describes the proof of concept software system developed to validate the cost impact analysis methodology created in chapter 6. The internal cost impact analysis architecture is implemented in a prototype system. The system is completely independent of any software development environment, it concentrates purely on the problem domain and it is not concerned with how the solution is to be achieved. Therefore, cost impact analysis can be implemented in any chosen programming environment. The system will aid the validation cost impact analysis methodology and facilitate reuse the design requirements within the automotive industry.

Chapter Aim:

To develop a proof of concept software system to implement cost impact analysis methodology.

This chapter describes the conceptualisation of cost impact analysis methodology. This chapter will provide insight into the rationale behind some assumptions and decisions made in the development of the CIAM program. The rest of the chapter is structured as follows: Section 8.2 provides a general overview of the CIAM system architecture design model by addressing the systems requirements, and describes the analysis and design of the software system. Section 8.3 discusses the selection of a development environment by evaluating three main development environments. Section 8.4 discusses the implementation of the database using MySQL, the OEM interface using VB.NET and the supplier interface using VB.NET. Section 8.5 presents the test case and validation of the software. Section 8.6 discusses the systems deployment, maintenance issues and the future enhancement that can be made to the software. Section 8.7 presents the key observations. Finally, the chapter is summarised in section 8.8

8.2 Requirements

The software analysis stage starts with the clarification of requirements. The successful development of the software system entails that the requirements are stated clearly. The application domain of the software must be described before requirements can be expressed (Bjorner, 2002). This chapter outlines the activities required to develop a software system. The previous chapters have provided an understanding of the domain. The requirements are modelled using Microsoft Word as illustrated in Figure 8-1 and Appendix G. Figure 8-1 illustrates the propagation window. The XXs are the requirements and extent indicates the degree of impact (Strong Medium or Weak). These screens help to identify information required for the system implementation.

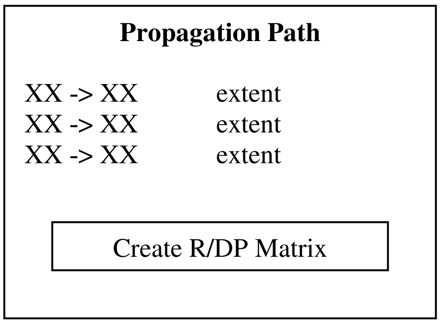


Figure 8-1: Initial Sample Screen (designed by hand)

Cost impact analysis has been divided into three subject areas: design changes, impact analysis and cost estimation. Cost impact analysis methodology has four phases (prerequisite, inputs, process and output); the last three forms the main foundation of the system. The conceptualisation is a VB.NET application where the users interact with the system using windows dialog boxes, the system provide visibility across OEM and Tier 1 Supplier relationships. The system architecture is client/server. The software system estimates the cost of proposed design requirement changes of a mechanical product. This is achieved by implementing the three subject areas, using proven and widely accepted principles. The system decomposes a mechanical design product into hierarchical structure of requirements, design parameters and constraints. The system then converts the hierarchical structure into matrixes showing relationships between the requirement and design parameters. The degree of the relationships is represented in Table 8-1.

Table 8-1: Extent of Impact

S	Strong	requiring new manufacturing tool
M	Medium	requiring major modification
W	Weak	requiring minor modification

8.2.1 Potential Users of the Prototype System

The proposed methodology can be used by OEMs and suppliers for making project decisions. Within the OEM organisation, Project managers can use the software when approving change requests. It is expected that OEM project managers would be interested in the feasibility of a proposed change. The software reduces rework time since there is visibility of interconnectivity between elements of the product. Design engineers will also be able to assess the possibility of subsystem interrelationships before detailed design phase.

Suppliers will benefit from the methodology from various perspectives. Supplier project manager can make economic/profitability decision before committing resources to the implementation of any proposed change. The software provides better understanding of system links at an early stage of the design phase (before detail design, 2D/3D drawings). The product development team (PDT) will be able to assign tasks/action early in the product development process. There is less opportunity of overlooking/omitting nontrivial issues. The methodology will aid the PDT in identifying issues before detailed design stage.

Additionally the software can be used as a training tool for new employees and for presentation in conflict resolution meeting. Both OEM and suppliers can find the software useful for analysing change request and understanding of conflict between requirements. The methodology can also be used to assess work to be done and unveil hidden issues.

8.2.2 CIAM Architecture

The CIAM system is distributed software that integrates the design requirements change management activities of both the Original Equipment Manufacturer (OEM) and the Tier 1 Suppliers, as depicted in Figure 8-2.

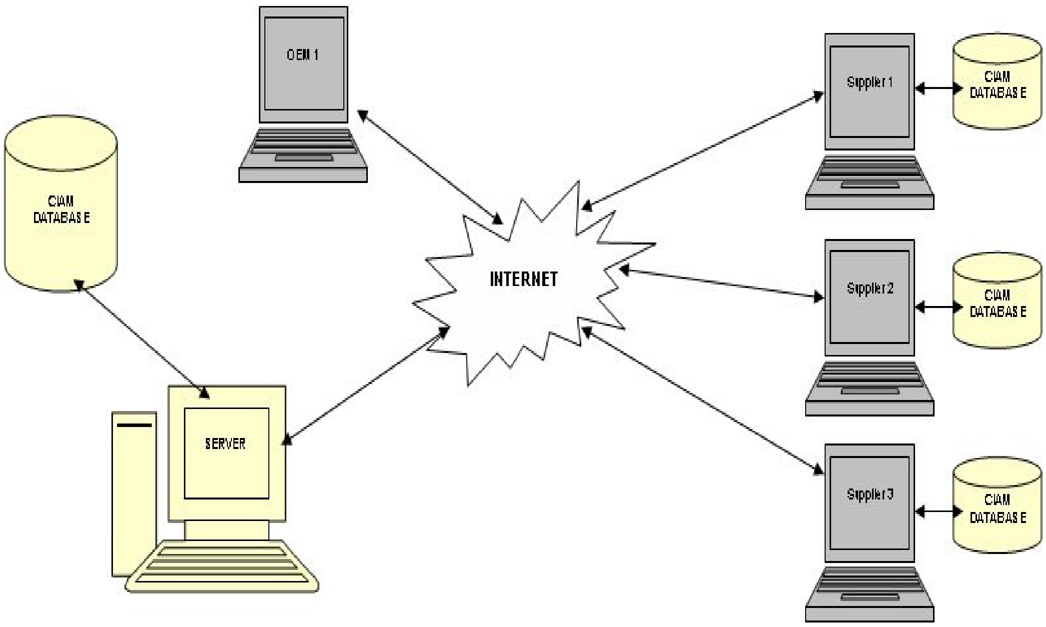


Figure 8-2: CIAM Architecture

There are two major interfaces in CIAM. These are the OEM interface and the Tier 1 Supplier interface. The CIAM system is developed in Visual Basic.NET framework using MySQL database management system (DBMS). This system is the prototype version 1.0.

8.2.3 Analysis of Prototype

The main purpose of the analysis stage is to ensure that all items in the requirement summary are fulfilled. This stage starts with an initial use-case diagram and an initial class diagram. These are modified iteratively as more understanding of the system is gained during the development process.

Use Cases

Figure 8-3 illustrates that a designer (Actor) makes a design requirement change, determines the impact that change has on other requirements. The cost of implementing the change is determined; finally a report is generated to reflect the change origin, the affected requirements, design parameters and constraints.

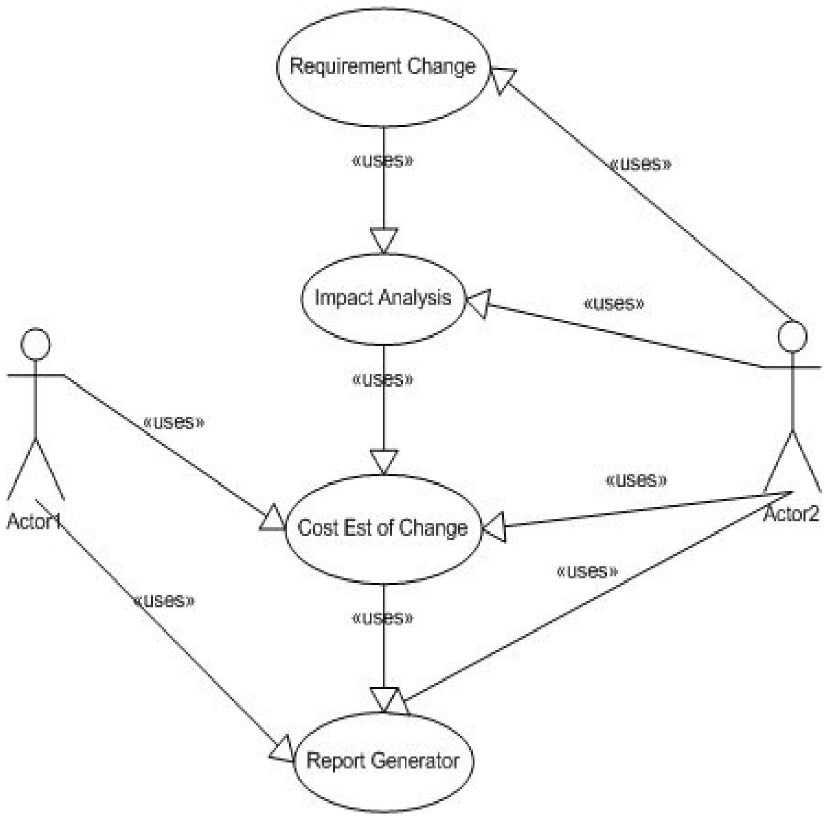


Figure 8-3: Initial Use-Case Diagram

Class Diagram

Figure 8-4 illustrates the initial class diagram which indicates the relationships between the identified classes. The class diagram is generated as a result of the initial use-case. The classes reflect the initial view of the developer. The system class inherits data (SystemID, ProductFamilyID) and methods (getSystemName(), getProductFamilyName()) from the supplier class, while the subsystems class will inherit data (SubSystemID, Product FamilyID) and methods (getSubsystemName(), getProductFamilyName()) from the system class.

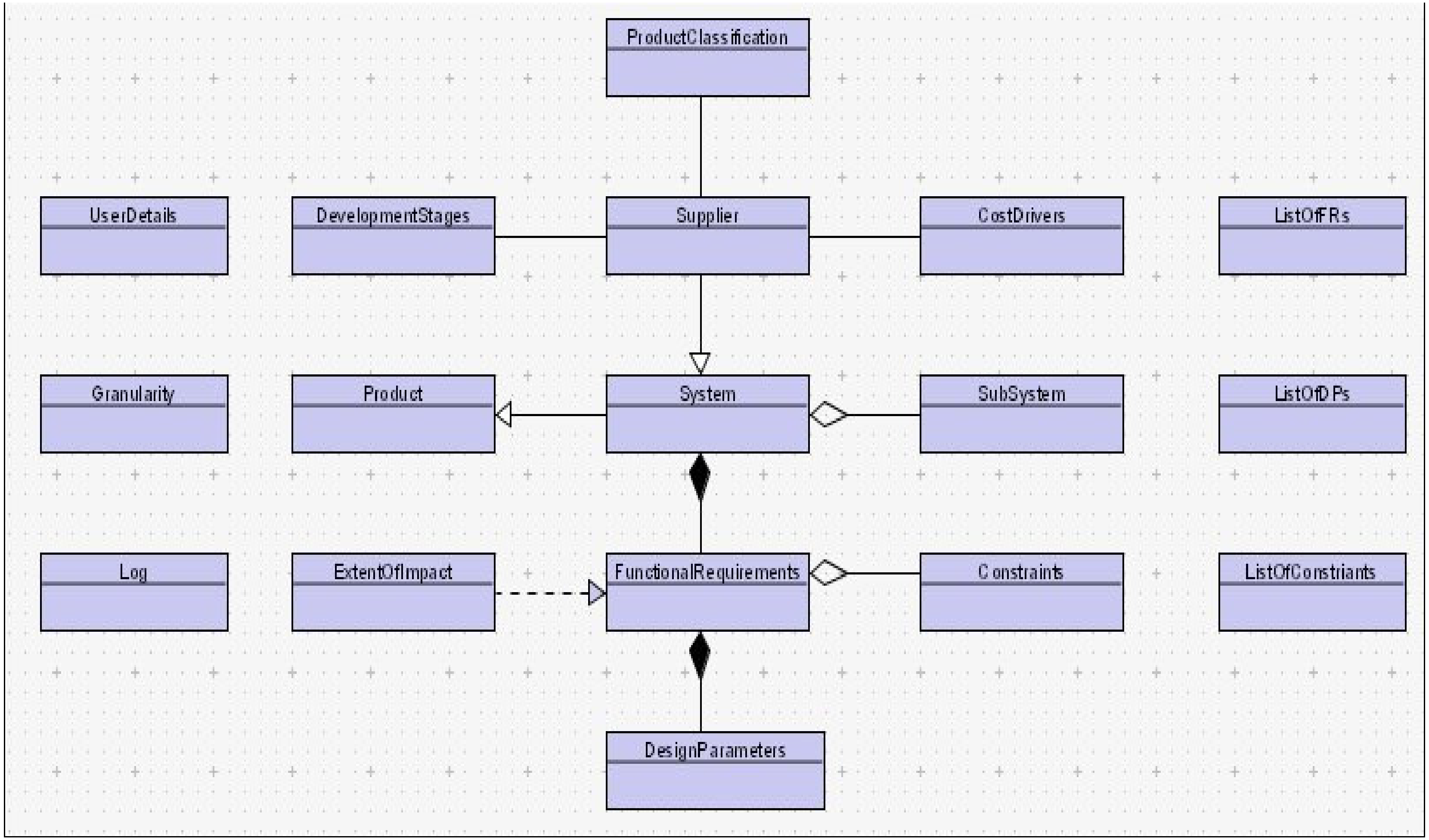


Figure 8-4: Initial Class Diagram

Database

From the initial class diagram in Figure 8-4, database tables and schemas are created. A few of the identified table are shown in Figure 8-5, while the rest of the database tables are in Appendix G. Product table will need to be identifiable, hence the need for a product id, product name, product description and probably an image of the product (which can also be stored on the database).

Product (Prod_ID, ProdName, ProdDescrip, ProdImage)
System (ProdID, SystemID, SystemName, SystemDesrip, SyetemImage, SupplierID)
SubSystem (SystemID, SubSystemID, SubSystemName, SubSystemDesrip,
SubSystemImage, SupplierID)
FunctionalRequirement (SystemID, SubSystemID, FRID, FRDescrip)
Constraints (FRID, ConstID, ConstDescrip, {Range upper to lower})
DesignParameter (FRID, DPID, DPDescrip)
CostDriver (CostDriverID, CostDriverName, CostDriverDescrip)

Figure 8-5: Database Tables and Schema

A data flow diagram is created to show the relationships between the database tables as depicted in Figure 8-6. They are used to create database tables on the DBMS. For example the requirements are related to a system and many design parameters, while subsystems are related to a system.

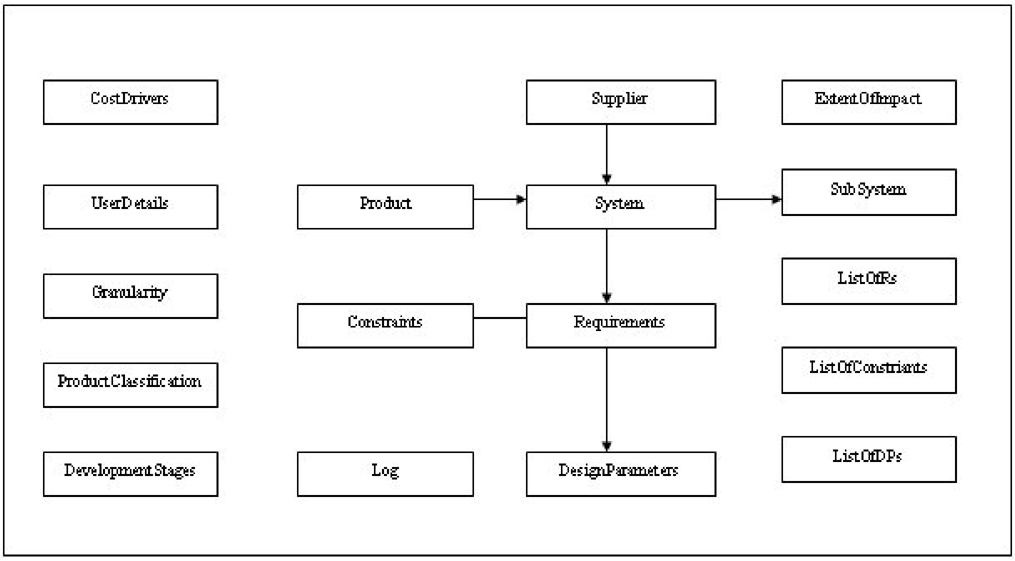


Figure 8-6: Initial Data Flow Diagram

The next stage is the design stage, which identifies the database tables and the classes. Rational unified process (RUP) is the method used for the software development. Unified modelling language UML was used to analyse and design the software system. RUP helps to structure the software development life cycle, by iterating across the modelling language UML. An initial use case is created, and then an initial class diagram is developed. The developer will revisit (iterate) the use case for refinement. This process of iteration continues until after the program development.

8.2.4 Design of the Prototype

The design stage shows how the system will be realised in the implementation stage. The design stage also shows the performance of the system in a specific implementation environment, the tasks and functions specified in the use-cases. When a requirement change is proposed within the automotive products, the proposed change may sometimes affect other parts. The system should enable estimators to minimize errors caused by missing design and/or specification information; allow estimators to "visualize" design information and to "structure" their thinking; Estimators can efficiently be trained in the intricacies of impact analysis and cost estimating by using the proposed system.

Use Case Refinement

Software development is an iterative process, the use-case in Figure 8-3 is refined by adding more functions to the system as illustrated in Figure 8-7. The use case diagram shows the relationships between the actors (Estimator and Administrator) and the system functions (Create matrix, generate propagation path, etc). These functions are broken down further by representing them as collaboration and sequence diagrams. These functions are then implemented in the software system. These will aid the code development stage, as it shows interfaces that are required i.e. matrix creation window and propagation path window.

Class Diagram Refinement

Similar to the use-case, the class diagram is also refined to reflect the data and methods expected from the system, as shown in Figure 8-8. The classes are encapsulated i.e. data and methods are added to the classes.

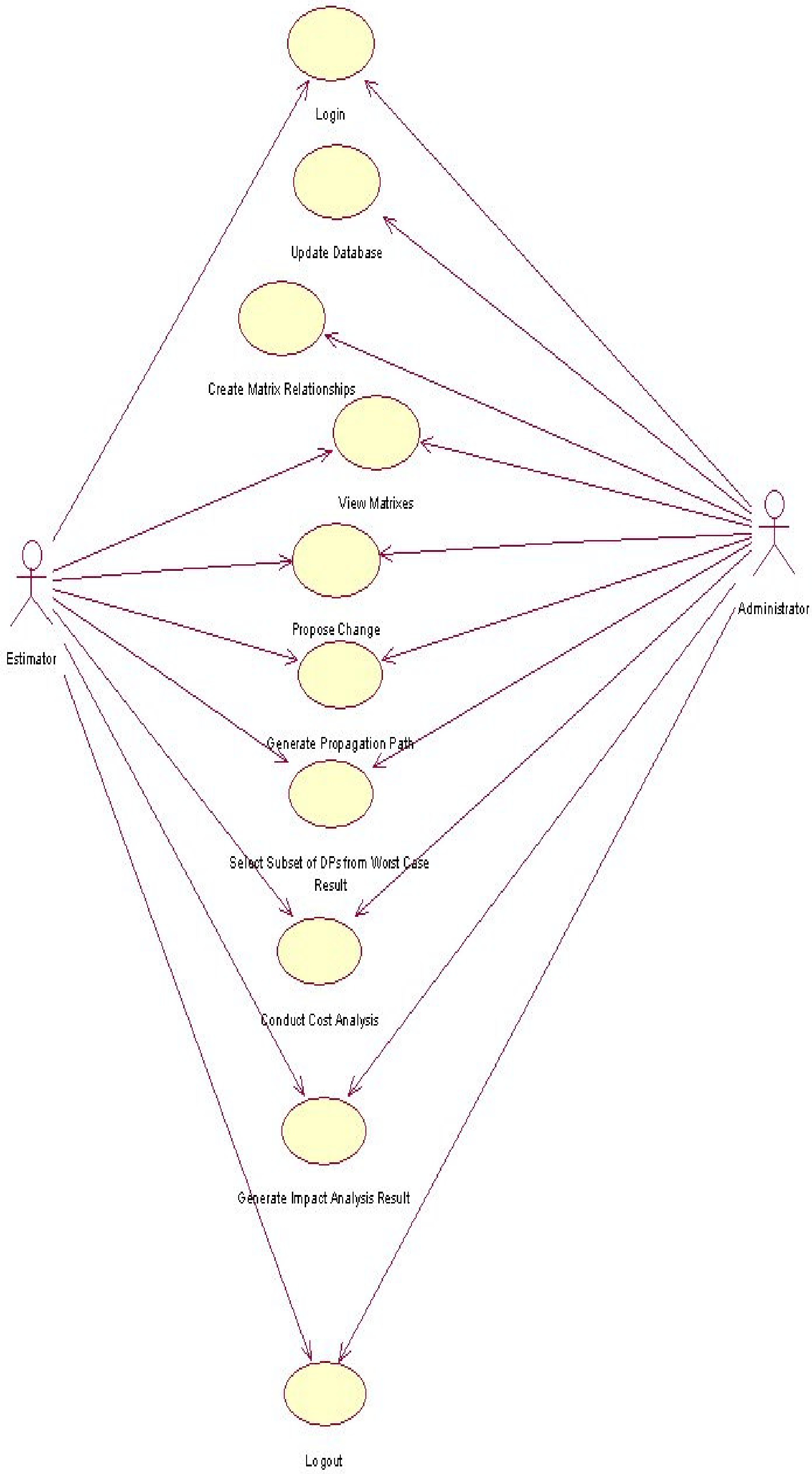


Figure 8-7: Improved and Reviewed Use-Case Diagram

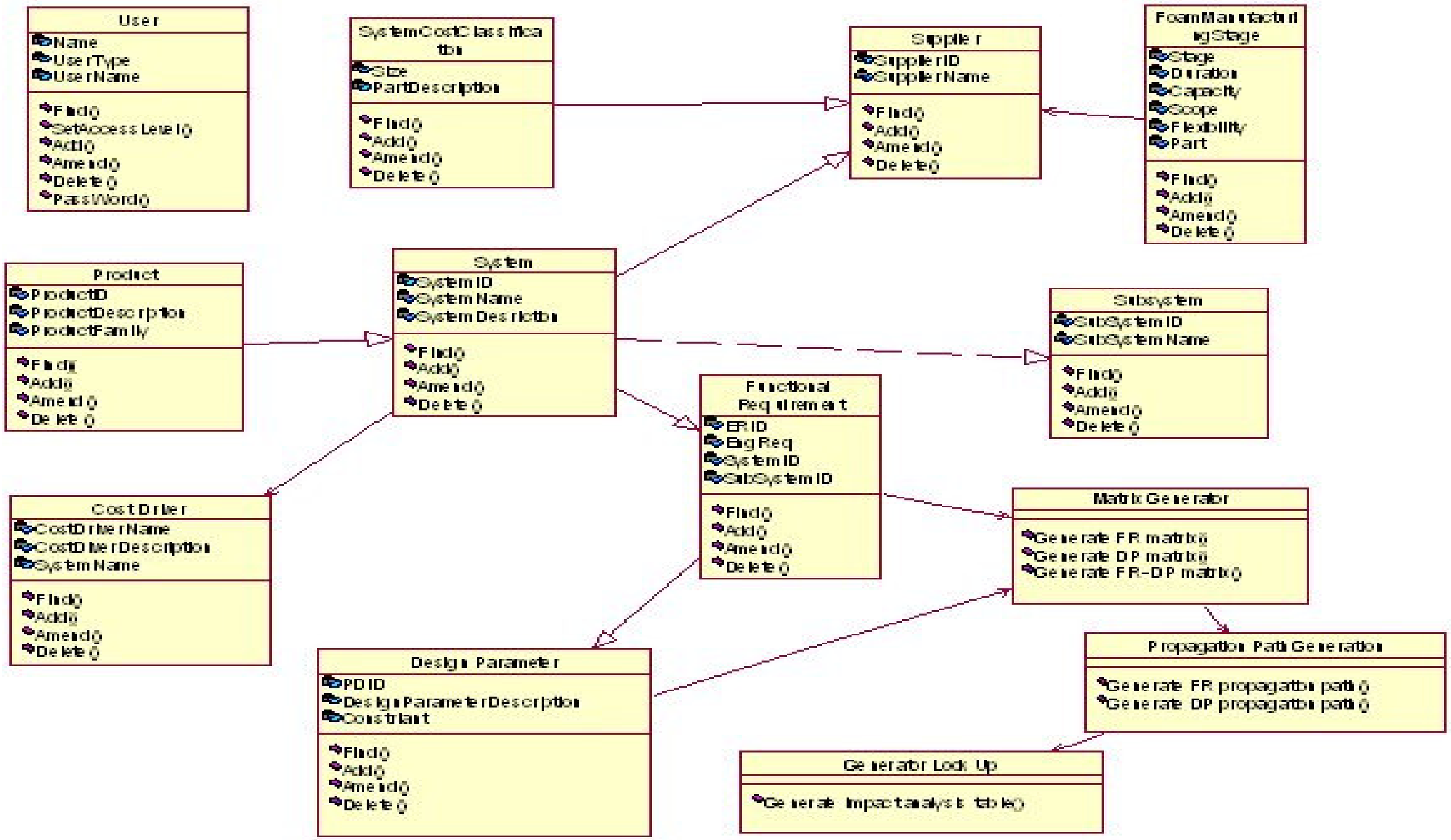


Figure 8-8: Refined Class Diagram

Transition

The transition stage involves mapping sequence diagrams (Figure 8-9) and collaboration diagrams (Figure 8-10) to the implementation environment. The next stage is the implementation stage, which is divided into three sections 1) MySQL implementation, 2) VB.NET for the OEM interface and 3) VB.NET for the supplier interface.

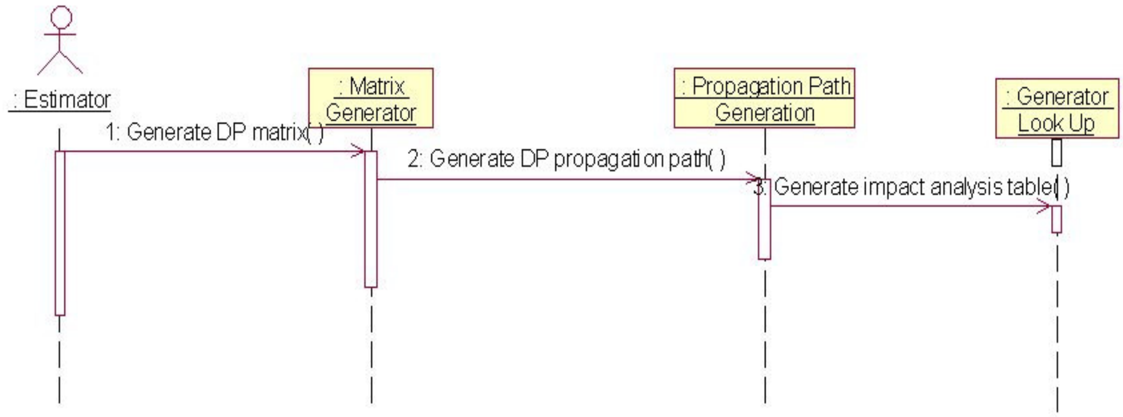


Figure 8-9: Sequence Diagram

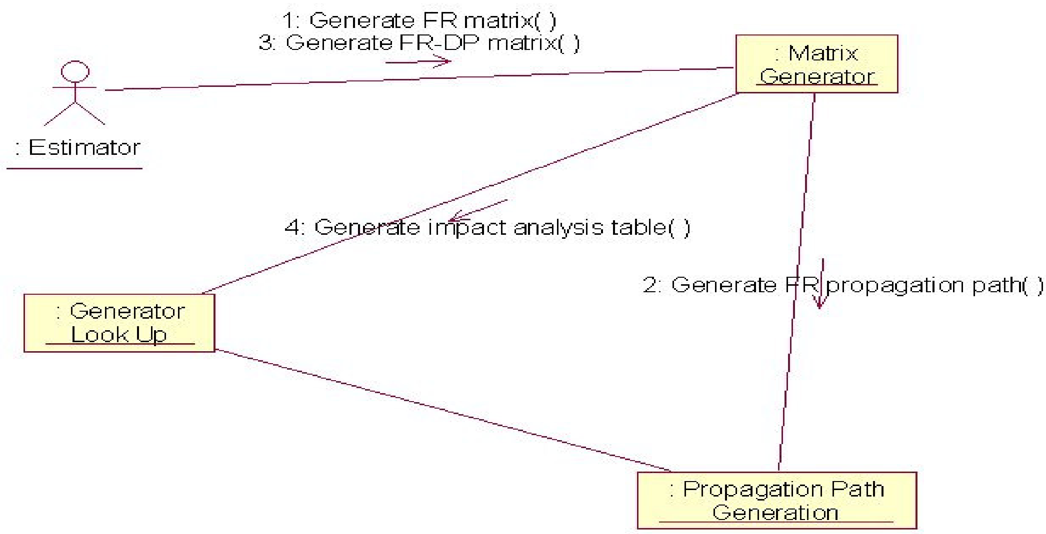


Figure 8-10: Collaboration Diagram

8.3 Selection of Development Environment

Three distributed application-programming environments were considered, CORBA, J2EE and VB.NET. All three were evaluated for scalability, price of licence, ease of use and portability of the software. Finally, VB.NET was chosen as the preferred programming environment. This decision was based on commercialisation potentials and migration of industrial collaborators to Microsoft.NET environment.

CORBA

CORBA (Common Object Request Broker Architecture) is an attempt to let computer applications work together over networks. It was devised by the private, vendor independent OMG (Object Management Group) standards committee. CORBA-based programs use the IIOP standard protocol to communicate. Implementations based on IIOP are available on a wide variety of operating systems, programming languages, and networks and are thus highly portable. The main drawback of CORBA is its rather low speed. While this may be tolerable in networks, it is a real hindrance for inter-application communications in a non-networked environment that runs on a single computer.

J2EE

Although Java and J2EE (Java 2 extended enterprise) have been extremely successful for a number of years, as they offer such a powerful solution for critical distributed applications. However, these technologies are seen as complex and reserved only for experienced developers. A number of J2EE projects fail because of the complexity of the J2EE framework in general, and of EJB (enterprise java bean) in particular. Although the J2EE API specification offers a standard way for developing distributed enterprise applications, it does not provide all the necessary building blocks. EJB tends to be complex and overused; and many J2EE design patterns are not design patterns but workarounds for technology limitations.

VB.NET

Visual Basic .NET (VB.NET) is an object-oriented computer language that can be viewed as an evolution of Microsoft's Visual Basic (VB) implemented on the Microsoft .NET framework. The main advantage in using VB.NET is its compilation speed and it is quicker to develop applications in VB.NET. Compared to CORBA and J2EE, it takes a long time to master VB.NET programming environment. However, development time is shorter than that of CORBA and J2EE.

Adopted Development Environment

Table 8-2 shows the comparison of all three development environments. All three environments are scalable system developed in these environments can be easily modified to fit various problem area. CORBA has four main vendors VisiBroker, Iona, Rogue Wave and ObjectSpace, who all sell their implementation of CORBA at various rates including academic rates. J2EE has several free implementations, such as Orion (www.**orion**server.com/), however it is not always easy to contact the Orion support team. Other implementations, such as JBOSS, WEBSPHERE and WEBLOGIC can be purchased at academic reduced cost. VB.NET can also be purchased at academic discounted rate. J2EE and VB.NET are easier to learn and understand than CORBA. Portability of J2EE from windows to say UNIX can be achieved with minor changes to the code. While VB.NET only operates on windows environment and CORBA applications is operating system specific.

Table 8-2: Evaluation of Development Environment

	CORBA	**J2EE**	**VB.NET**
Scalability	Yes	Yes	Yes
Price	£ 2,000.00	Free	£ 2,000.00
Licence	£ 1,000.00	Free	£ 600.00
Ease of Use	No	Yes	Yes
Portability	No	Yes	No

One of the objectives of the sponsoring company is to integrate CIAM with other systems in the future. VB.NET environment is well supported by Microsoft and has many online user groups. VB.NET is object oriented; it facilitates reuse and is extendible. The general structure of the application model is defined in the architectural design model, which specifies systems and subsystems decomposition. MySQL was chosen as the preferred database management system (DBMS). MySQL is a free open source application; it is well supported and has many online user groups.

8.3.1 Database Implementation using MySQL

MySQL is used as the database management system (DBMS). There are basically 2 main databases namely the OEM and the Supplier databases. It is expected that OEM will not want to share all data with suppliers and vice versa. The Entity Relationship Diagram and database tables used for CIAM are shown in Figure 8-5 and Appendix G. These tables and fields are stored in a database called ‘e_RM_supplier_db. A second database exists for OEM database (e_RM_OEM_db). . In future it is envisaged that the engineering requirements (explained in the next section) will be replicated on the supplier database (e_RM_supplier_db).

The next section discusses the software implementation. The system was implemented in visual basic dot net (VB.NET) (Duncan, 2001). MySQL was used for data management (Edward, 2000).

8.4 Implementation

8.4.1 OEM Interface Implementation using VB.NET

The OEM Interface is where most administrative activities such as entering, deleting, and updating requirements take place. This is intended as the hub of the e-RM system for which other system will be integrated. CIAM system described in chapter 6 is one of such system that will be integrated to the e-RM system. Initial interfaces are drawn by hand and then Microsoft word, as illustrated in Appendix G. VB.NET has an integrated development environment (IDE) that allows developers to create dialog windows to input and output values to the screen. The subsequent section discusses the creation of the dialog windows.

Logon

The first step is to double click on the CIAM Application package so that the system starts. The user is presented with a Logon interface, as shown in Figure 8-11. There are three fields to type in. These fields are the Server, Username, and Password, shown in Figure 8-11. When the user types in the correct information for these fields, the user is allowed access to the system. If one or more of the fields are typed wrongly, access will be denied. This serves as a form of security check against unauthorized users.

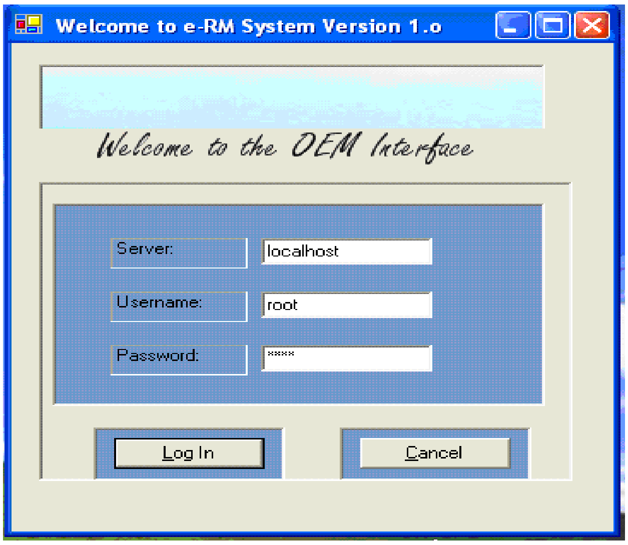


Figure 8-11: Entering Access Logon Information in the Logon Form

OEM Main Menu

If a user successfully Logon into the system, the OEM main menu interface appears, as illustrated in Figure 8-12. This consists of three main tabs namely Engineering Requirements, Customer Requirements and Business Requirements. Although Business requirements and Customer requirements are discussed, they are not used for Cost impact analysis, they are used in a sister project on electronic workflow mentioned in section 1.1.1. All entries are stored in the e_RM_OEM_db database.

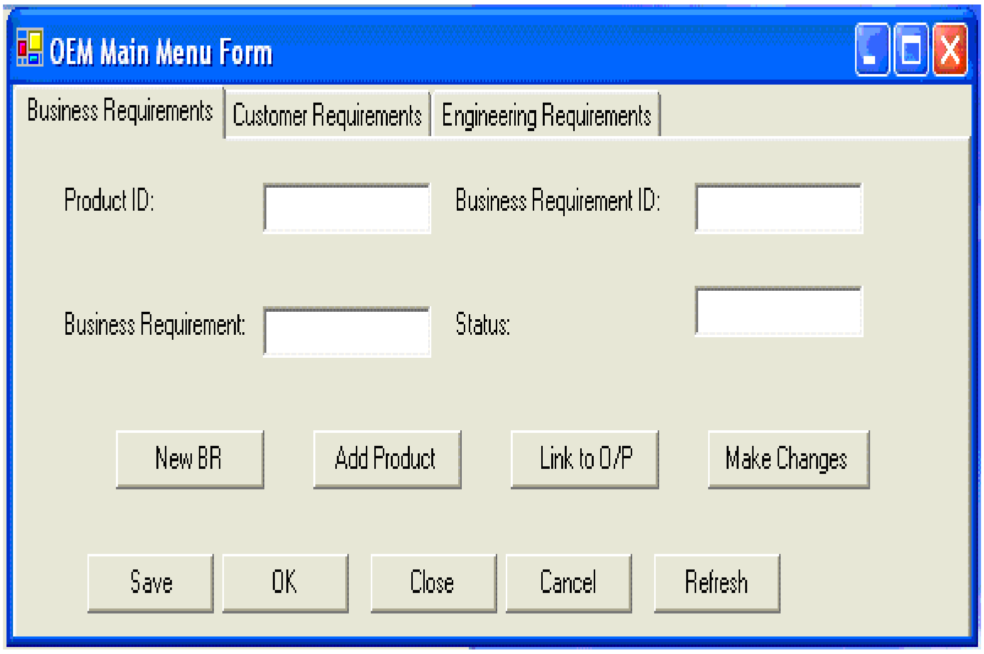


Figure 8-12: OEM Main Menu Form

Business Requirements

The Business Requirements tab consists of four fields namely ProductID, Business RequirementID, Business Requirement, and Status. There are nine command buttons. The New BR initiates blank fields for the four fields after entries have been made and saved. The Add Product button allows the addition of a new product (e.g. car), as shown in Figure 8-15. The Make Changes button allows the user to make changes to the business requirements.

Customer Requirements Tab

Figure 8-13 shows the Customer Requirements tab, which consists of five fields. It consists of eight buttons. The New CR button creates new customer requirements. The Make Changes buttons makes changes specifically to the customer requirements table only.

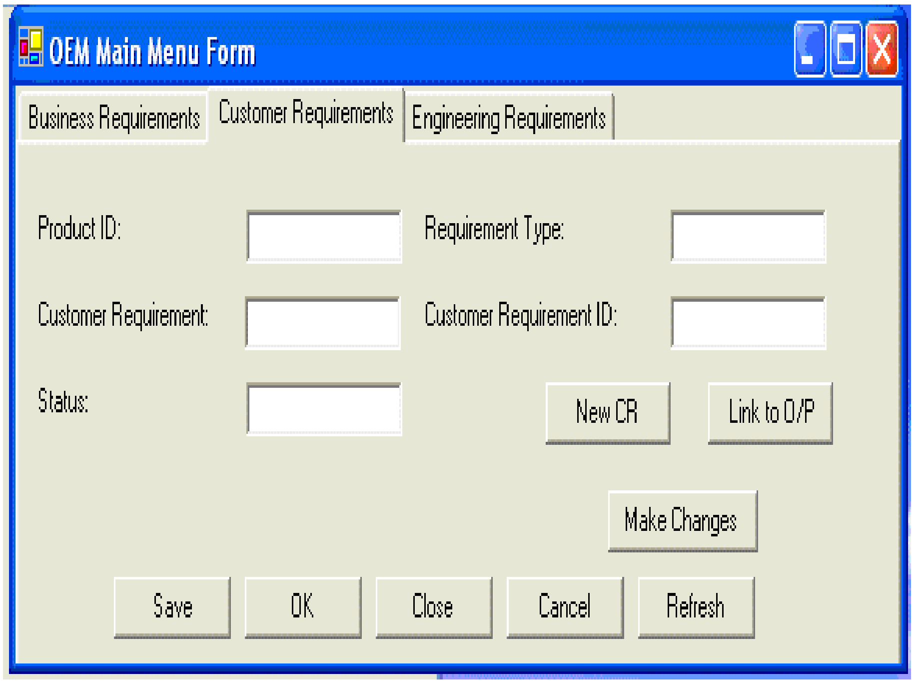


Figure 8-13: The Customer Requirements Tab

Engineering Requirements Tab

Engineering requirements refer to the system (e.g. car seating system, car cooling system, etc) requirements; similar to the business and customer requirement engineering requirements are entered here and stored in the e_RM_OEM_db database.

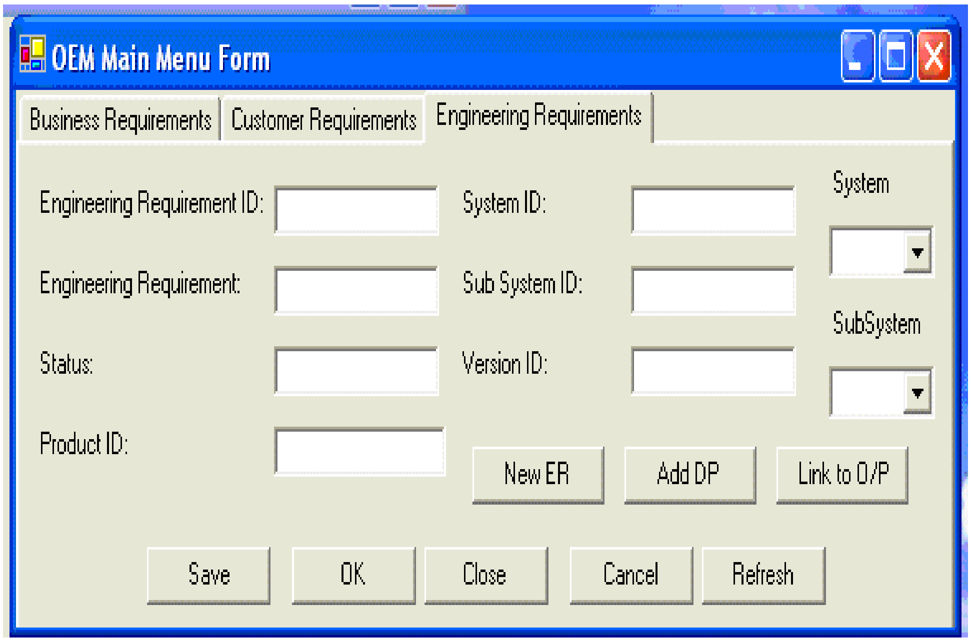


Figure 8-14: The Engineering Requirements Tab

The Engineering Requirements tab has nine fields and eight command buttons, as shown in Figure 8-14. The New ER creates new record for the Engineering requirements, Add DP adds a new design parameter and Link to O/P allows a user to make changes to the engineering requirements.

Making Changes to Requirements

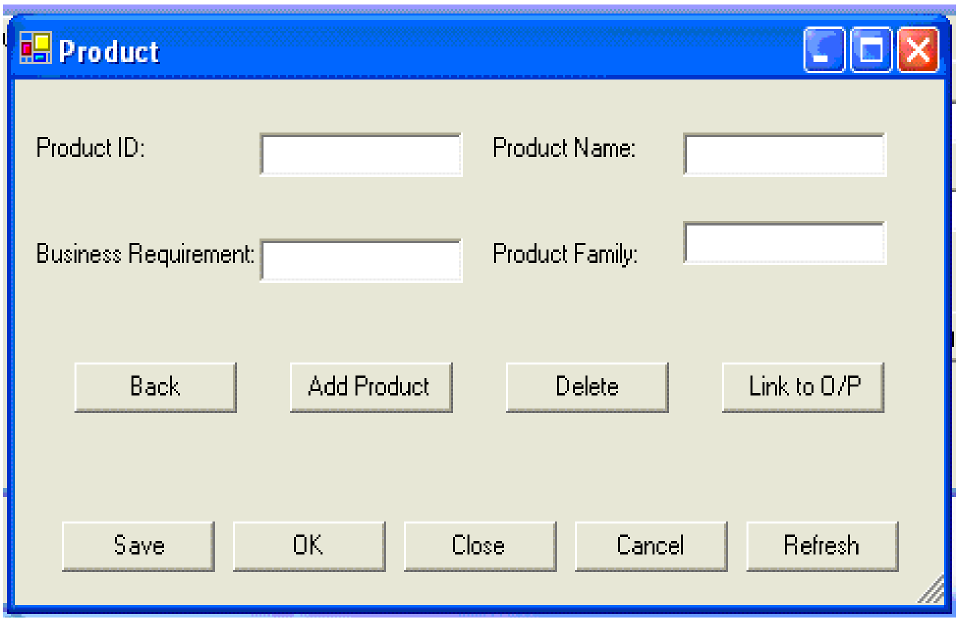


Figure 8-15: The Effect of Clicking the Add Product Button

Clicking the Make Changes button takes the user to the OEM Requirements Change Form, as depicted in Figure 8-16. This form has a Requirements Change Prompt, where the following SQL commands that can be performed to delete, insert, select entries from any database table. This allows authorised users to update the database tables.

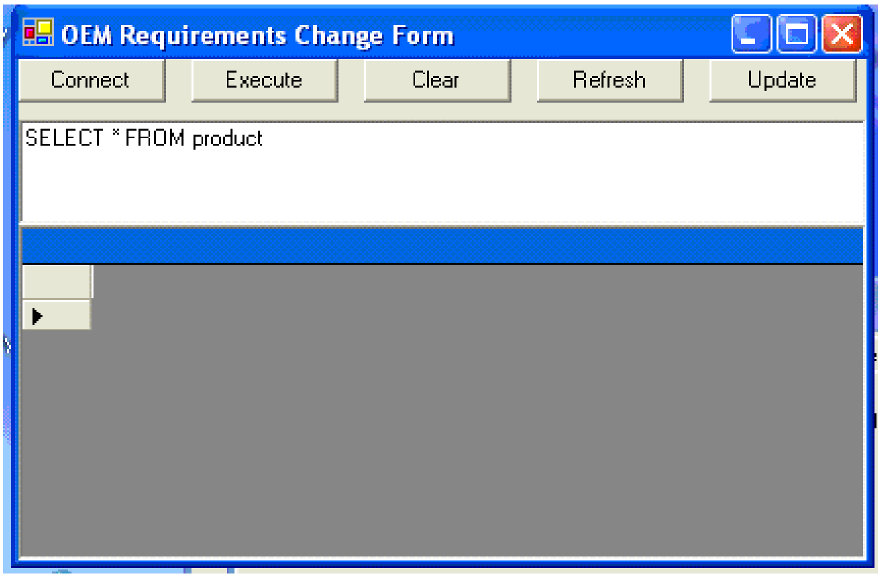


Figure 8-16: The Effect of Clicking the Make Changes Button

The OEM Requirements Changes Form has six command buttons. They are Connect, Execute, Clear, P-Path (Propagation Path), Refresh and Update. It is important to take some of the buttons and demonstrate their effects as it concerns requirements changes. The subsequent sections demonstrate the Connect, Execute, Clear, P-Path, and Update command buttons.

Connect command button

The Connect button provides a second level access to the user, as depicted in Figure 8-17. It must be noted that this is only possible if the user is already logged on. The first Logon allows the user access to the system and the OEM database only. This second level Logon will allow the user access to both the OEM and suppliers databases. In addition, it allows the OEM access to all versions of the databases.

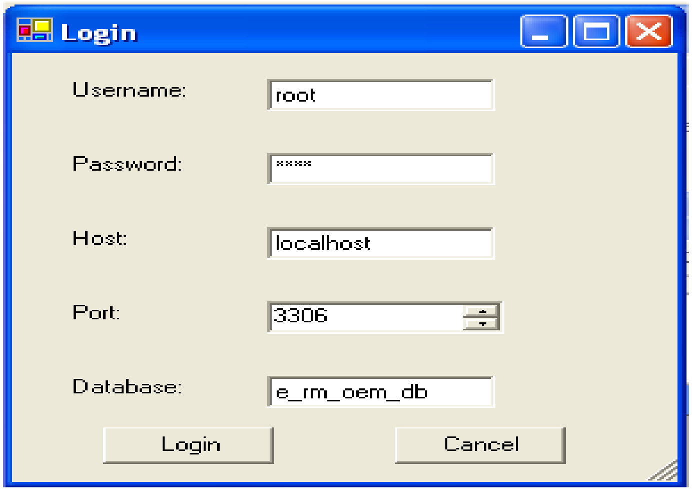


Figure 8-17: The Effect of Clicking the Connect Command Button

Execute command button

After a successful Login, the user types query commands at the OEM Requirements Change Command Prompt and clicks the Execute button to execute the command typed.

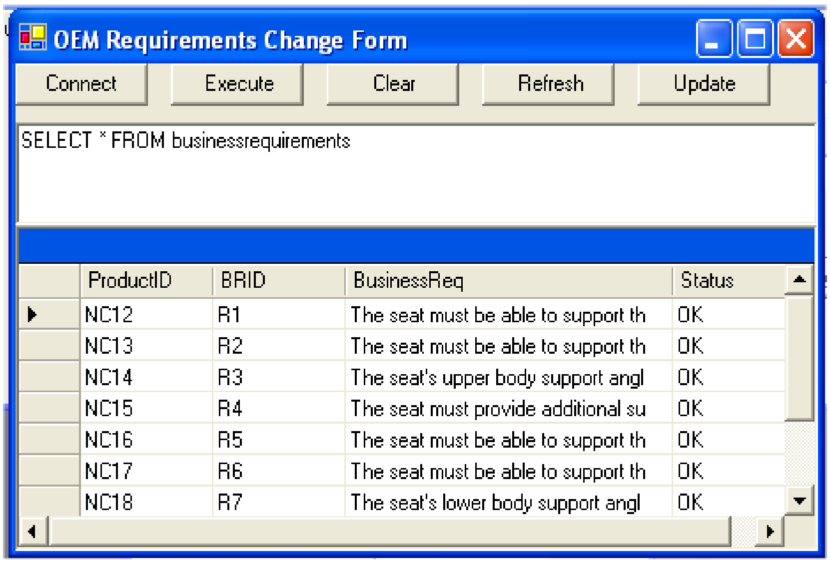


Figure 8-18: Execution of "SELECT* Statement

As illustrated in Figure 8-18, the contents of the business requirements were displayed due to the SELECT statement used. It contains the INSERT statement to add requirements or DELETE statement to remove requirements.

Clear command button

The clear command button clears the matrix to make it ready for another command to be executed. For example the Clear command button is clicked and another Select command is typed in to select all fields of the table called product. The table product is empty, so the user inserts a field, then updates it and clear, then execute it for the new record to be displayed.

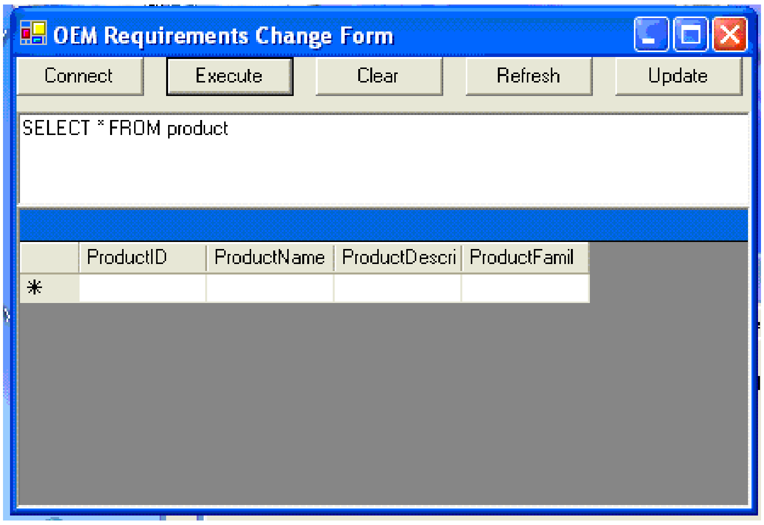


Figure 8-19: The effect of the SELECT * FROM product

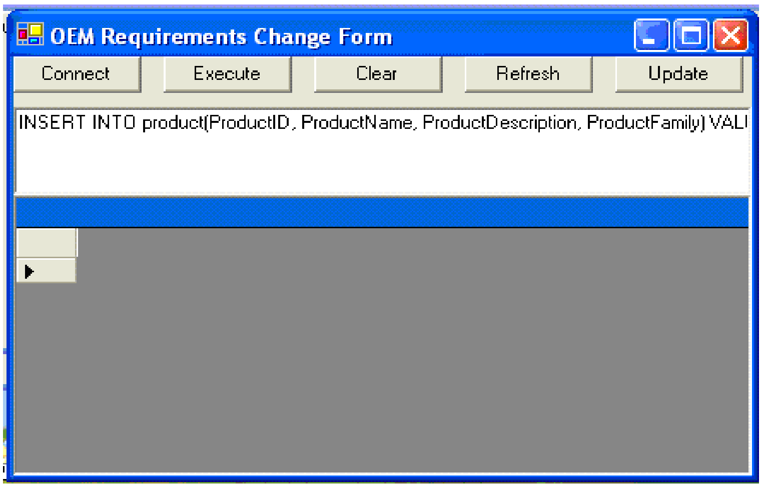


Figure 8-20: The INSERT Command

After clicking the Execute command button, the user clicks Clear and then type the SELECT * FROM product and then clicks Execute, as shown in Figure 8-19 and Figure 8-20. The newly inserted record appears, as shown in Figure 8-21.

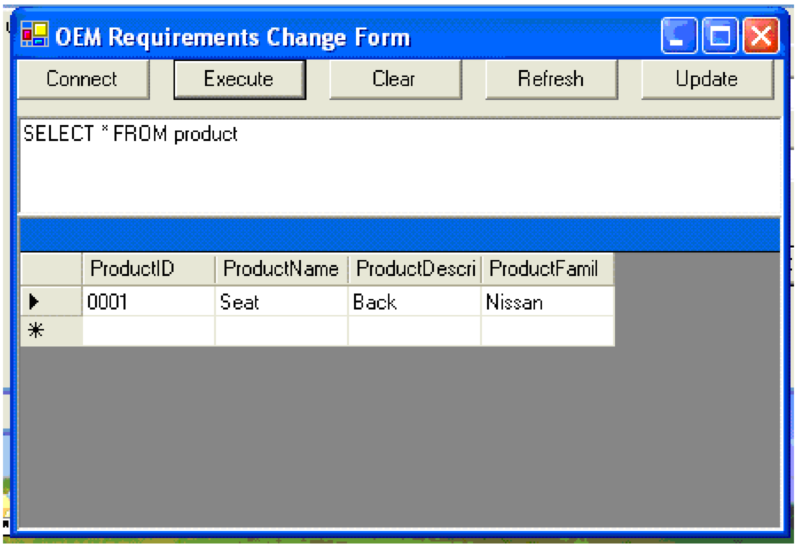


Figure 8-21: Newly Inserted Record

Update command button

The update command is used when insertion and deletion are made from the grid (matrix) forms directly without using the query commands. When the user insert or delete directly from the table displayed, changes are saved by clicking the Update command button.

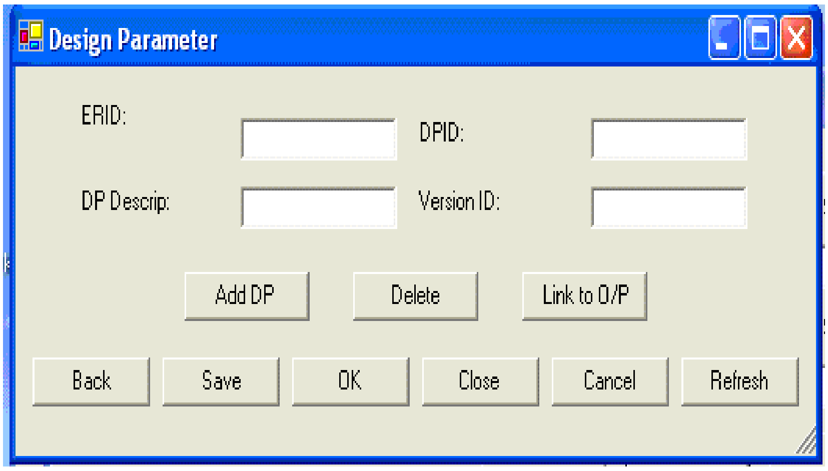


Figure 8-22: The Design Parameter Form

When a user clicks the DP button, the user is presented with the dialog box shown in Figure 8-22. This dialog box allows the user to enter design parameters and the requirements associated with them.

Generating Propagation Paths and Cost Impact Analysis Results

MySqlDirect.NET is used in conjunction with DPExplorer and MySql Databases to generate propagation paths and the associated cost impacts.

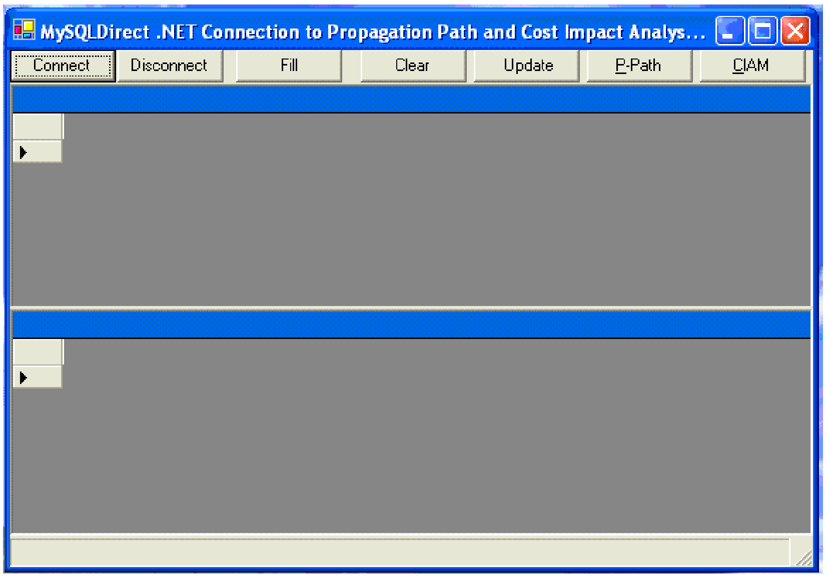


Figure 8-23: Pre-Connection Form

Clicking the buttons from the main form produces the Pre-Connection Form, as shown in Figure 8-23. To view the R-R matrix and later generate the propagation paths (PP) and the associated costs, the user clicks on CIAM button at the extreme top right hand corner of the Pre-Connection form.

The Cost Impact Analysis and propagation Path Form is partitioned into four, as demonstrated in Figure 8-24. The top left side has the R-R matrix; the top right has the affected DPs; the bottom left has the propagation path; and the bottom right has the cost impact analysis. Clicking the Connect button brings the connection form, as illustrated in Figure 8-32. Clicking the Connect button on the Connect form and the user is in the DPExplorer. This section has discussed the creation of the OEM interface as it relates to this research. The next section describes the supplier interface implementation.

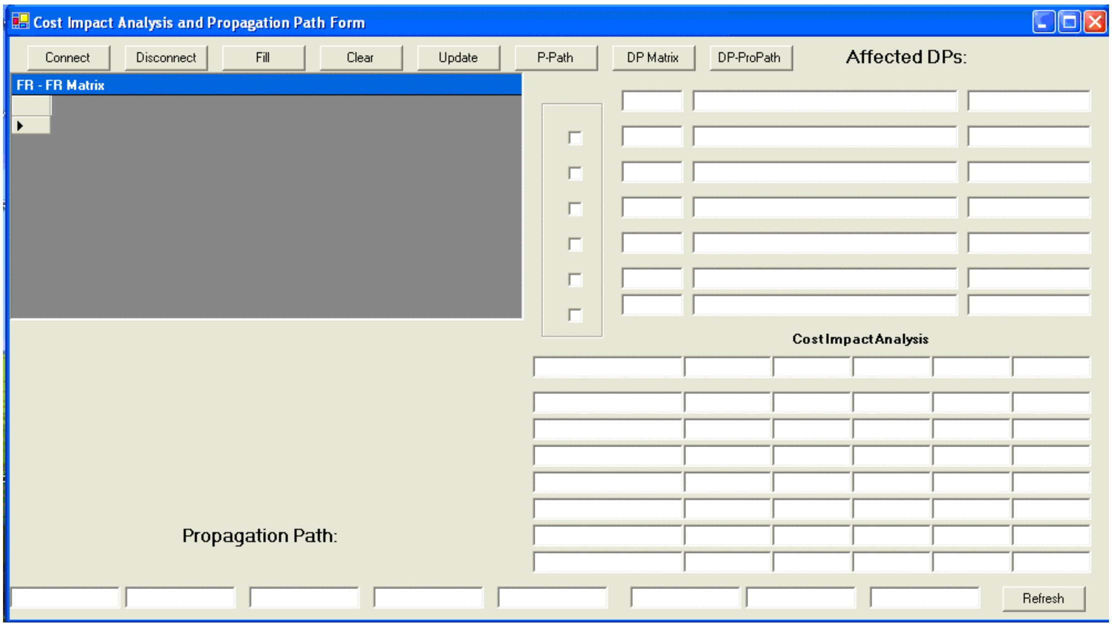


Figure 8-24: Cost Impact Analysis and Propagation Path Form

8.4.2 Supplier Interface Implementation using VB.NET

The supplier interface (CIAM system) is the other major interface of the e-RM system, as depicted in Figure 8-25. It consists of interfaces that allow suppliers to interact with the OEM requirements and make changes based on the OEM recommendations and supplier's resources. CIAM system has been implemented as a standalone system that can be integrated into the e-RM system.

Logon

Similar to the OEM logon interface, user CIAM will login to the supplier interface. MySQL database assigns access rights and privileges to users based on their usernames and passwords. As a user logs in, the user will only have assess to the tasks the system administrator has assigned to them. Most suppliers will not have rights to delete or insert into the databases, but can view all the contents of the databases.

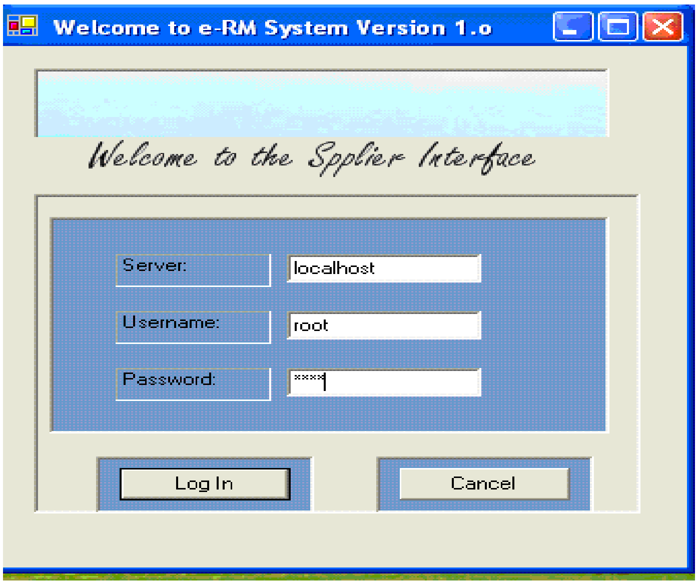


Figure 8-25: Supplier Login Interface.

The suppliers will also be able to input the right entries into the Server, Username and Password fields. The supplier main menu will appear when a user clicks the Log In button.

Supplier Main Menu

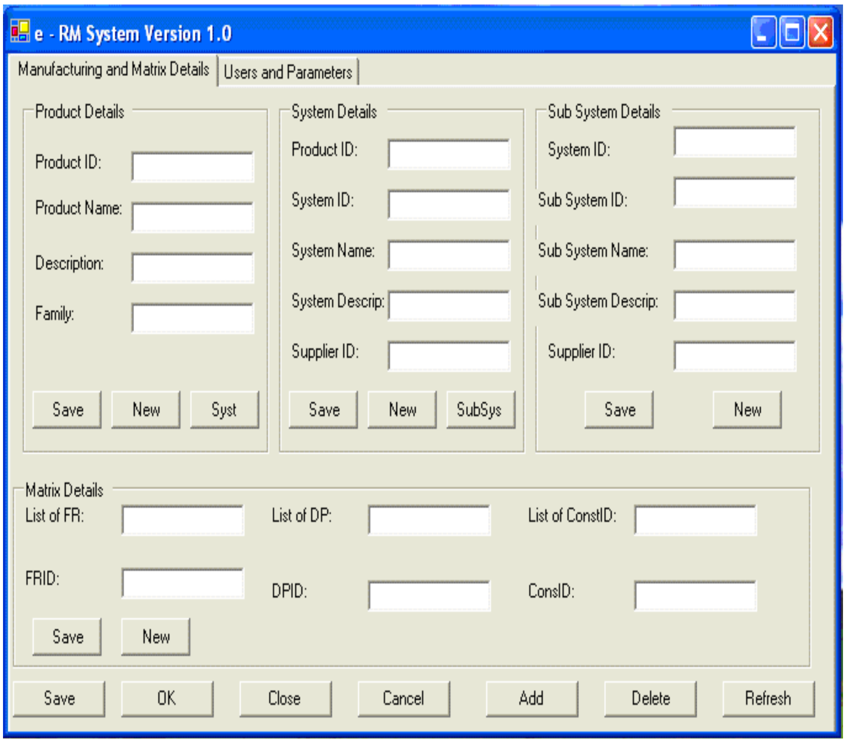


Figure 8-26: The Supplier Main Menu

The supplier main menu interface has two tabs. They are the Manufacturing and Matrix Details tab and Users and Parameters tab.

Manufacturing and Matrix Details Tab

The Manufacturing and Matrix Details tab is divided into four group boxes, as shown in Figure 8-26. They are the Product Details, System Details, Sub System Details, and the Matrix details. The user can make inputs on the fields within each group box and save it as many times as possible. These inputs are saved directly to the respective tables in the supplier database. For example, the Product Details information is saved into the product table in the supplier database.

Users and Parameters Tab

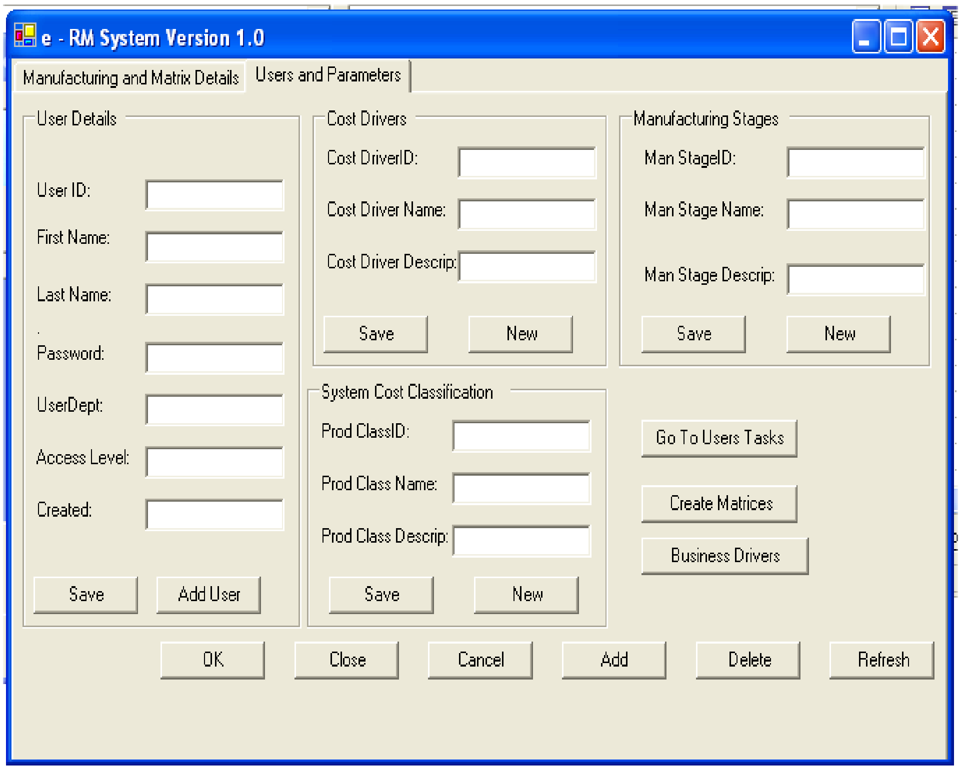


Figure 8-27: The Users and Parameters Tab

The Users and Parameters tab has four group boxes, as shown in Figure 8-27. They are User Details, Cost Drivers, Manufacturing Stages, and System Cost Classification. The inputs are saved directly into the supplier database tables. For example, inputs of Cost Driver group box will be saved into the cost driver table.

Business Driver Button

When the business driver button in Figure 8-27 is clicked the user is presented with the window in Figure 8-28, this window allows the user to enter the business drivers (cost and time driver). This information is required to select the right rule for the cost estimation.

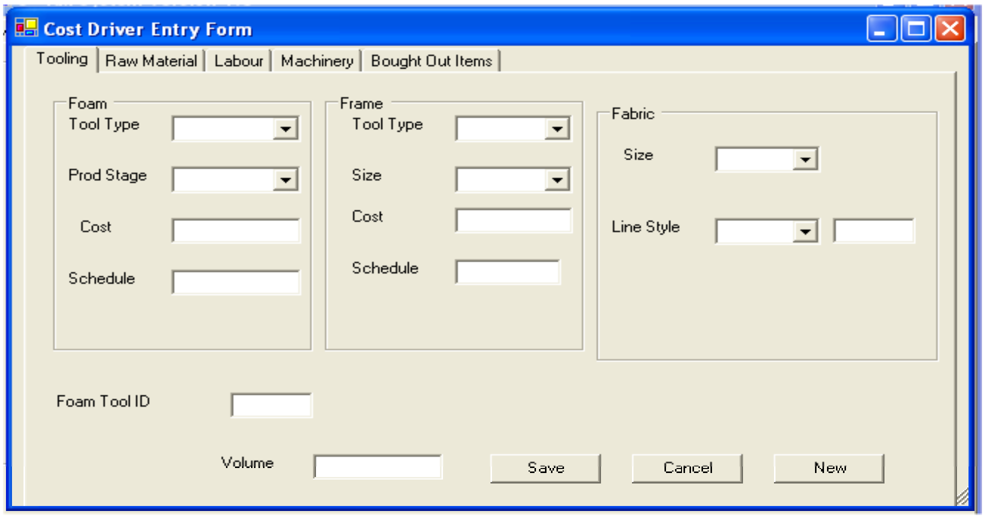


Figure 8-28: Business Driver Form

To display matrices the user clicks on the Create Matrices button, shown in Figure 8-27. Figure 8-29 is displayed; this window provides additional security to the system and allows users that have SQL query language experience to query database tables in the database.

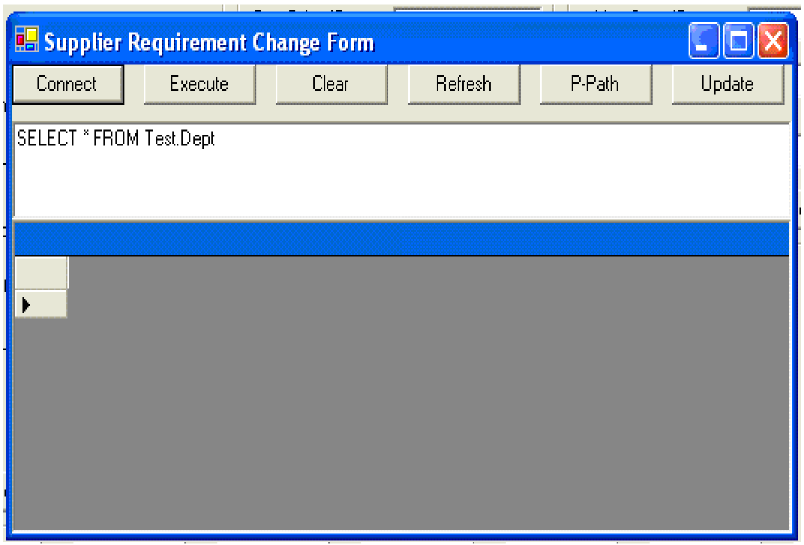


Figure 8-29: The Effect of Clicking the Create Matrices Button

Connect command button

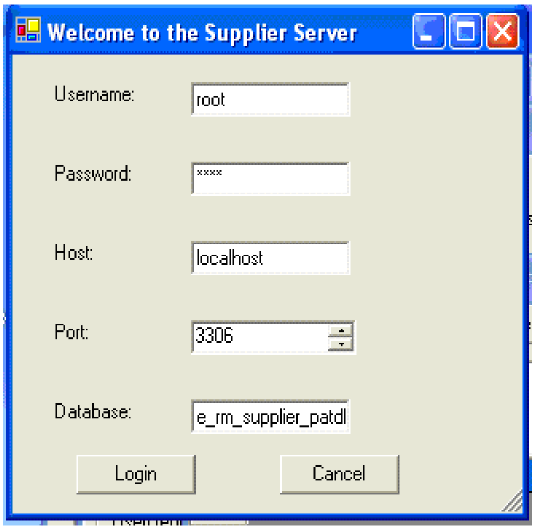


Figure 8-30: The Effect of the Connect Command Button

The Connect command button presents a second level Logon form that allows the user to access many databases, as shown in Figure 8-30. The user will type in the required fields and click Login.

Then the user will type "SELECT * FROM engineeringrequirements" at the Supplier Requirements Change Command Prompt and click the Execute command button, this will display the matrix illustrated in Figure 8-31.

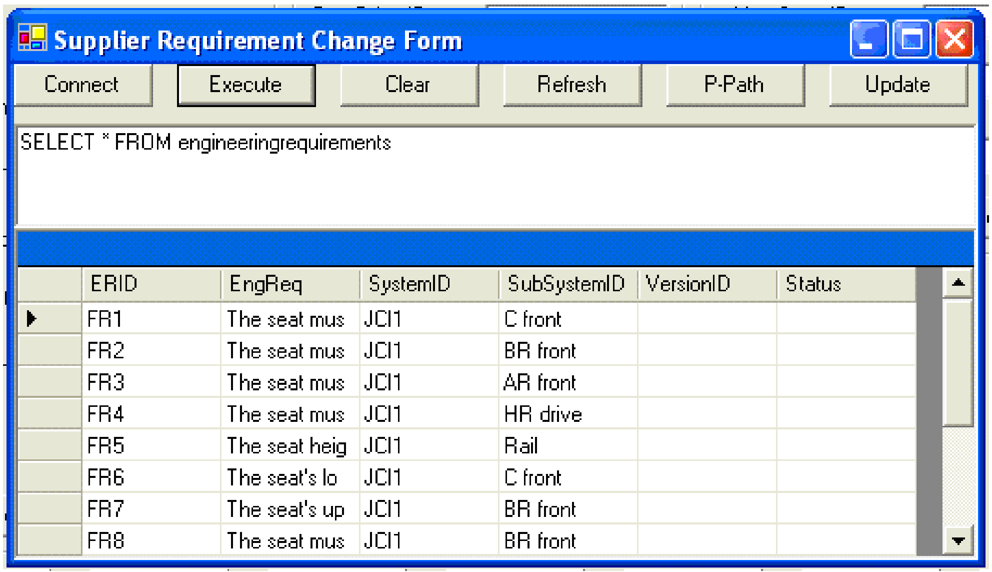


Figure 8-31: The Effect of the Execute Command Button

8.5 Testing and Validation

8.5.1 Test Case

To test the system after the database has been populated with the relevant data, a user needs to be connected to e_rm_supplier_db database. When connect button is clicked in Figure 8-31 the Figure 8-33 is displayed, here the user connects to the supplier database.

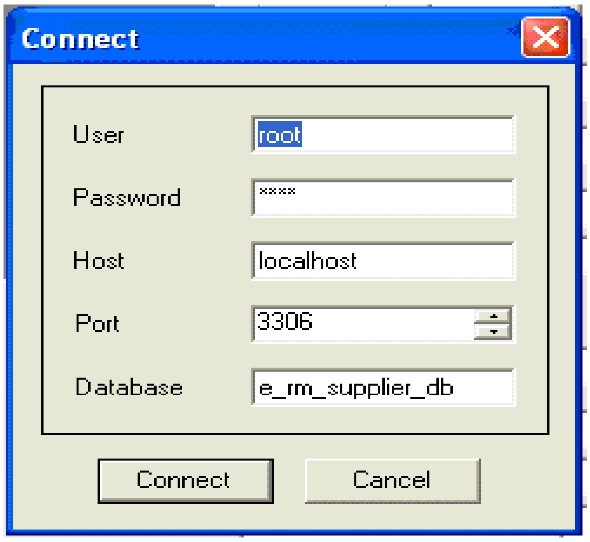


Figure 8-32: Connection Form

Clicking the Fill button on the R-R Data Grid form will fill in the R–R values as shown in Figure 8-33. This depicts the relationships between requirements of the system for which CIAM is applied. S in the data grid illustrates that there is a strong (S) relationship between the requirements. There are two other types of relationship medium (M) and weak (W), these two are not used in this demonstration.

Clicking on any of the extreme left side of any of the rows under R-R Matrix will generate the associated propagation paths, worst case affected DPs list and cost impact analysis respectively, as shown in Figure 8-33.

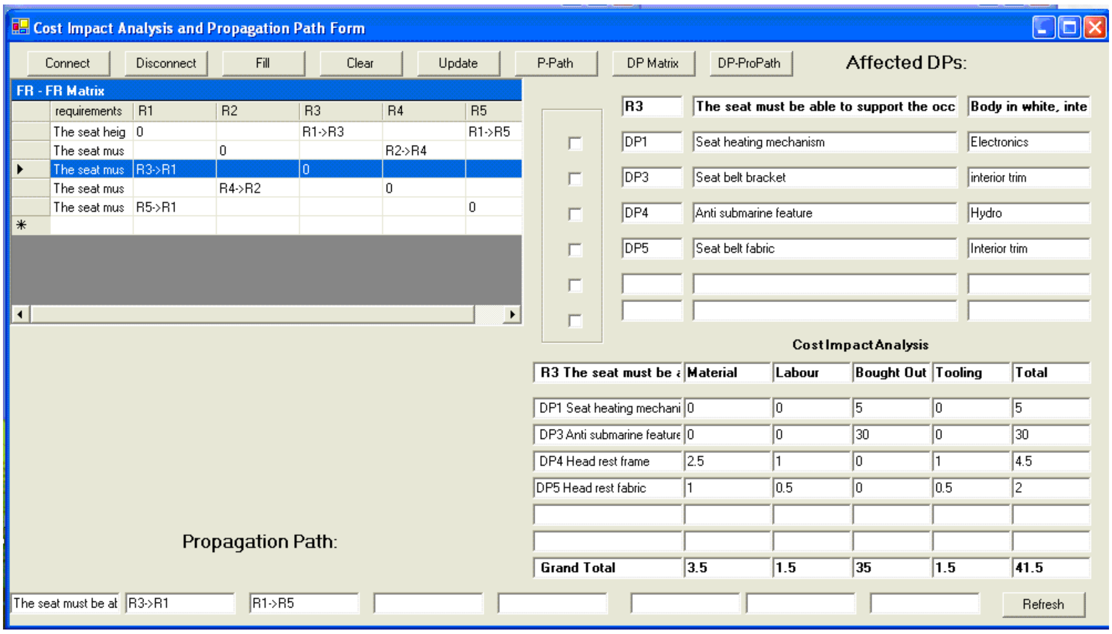


Figure 8-33: R-R Matrix, PP, DP, and CIA Produced for Row 3

If the user checks DP1 and DP4 on the affected DPs, then DP3 and DP5 will be removed from the affected DPs leaving only the checked DPs (DP1 and DP4). The cost impact analysis will also be affected by removing the associated cost incurred by DP3 and DP5; this is shown in Figure 8-34. When the user checks DP1 and DP3, then clicks the Refresh button, the incurred cost is updated.

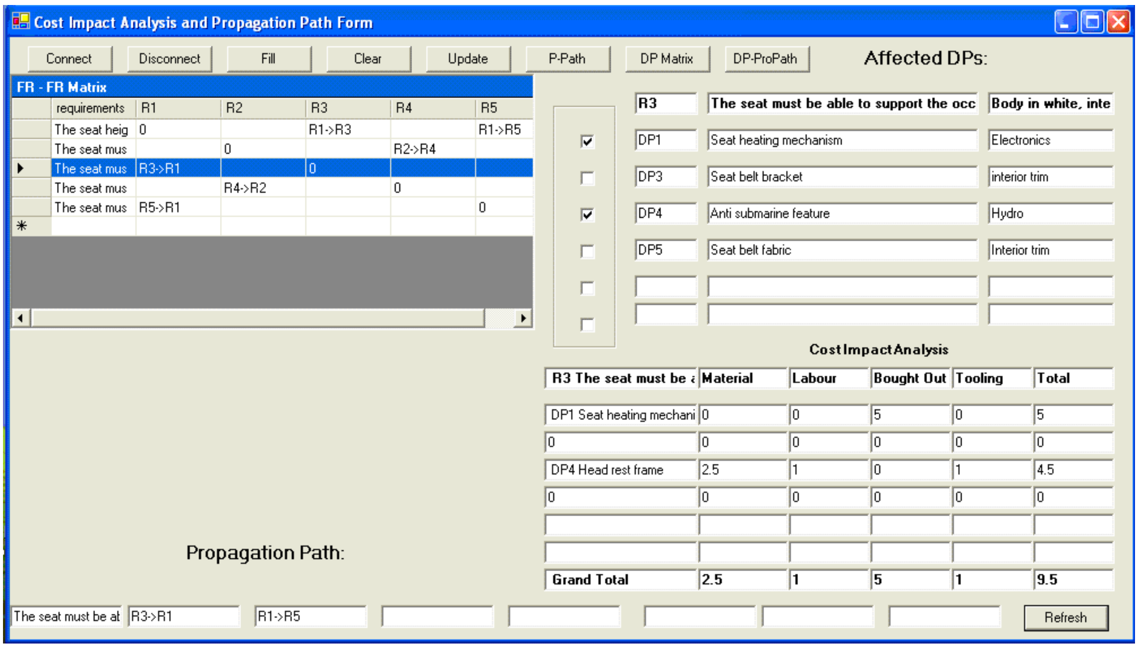


Figure 8-34: Cost Impact (when DP1 and DP4 are selected)

The R-DP matrix can be viewed by clicking the P-Path button on the "Cost Impact Analysis and Propagation Path" Form. To view DPs related to a requirement the user will click on the requirement and the affected DPs will be displayed in the lower halt of the FR-DP form, as illustrated in Figure 8-35.

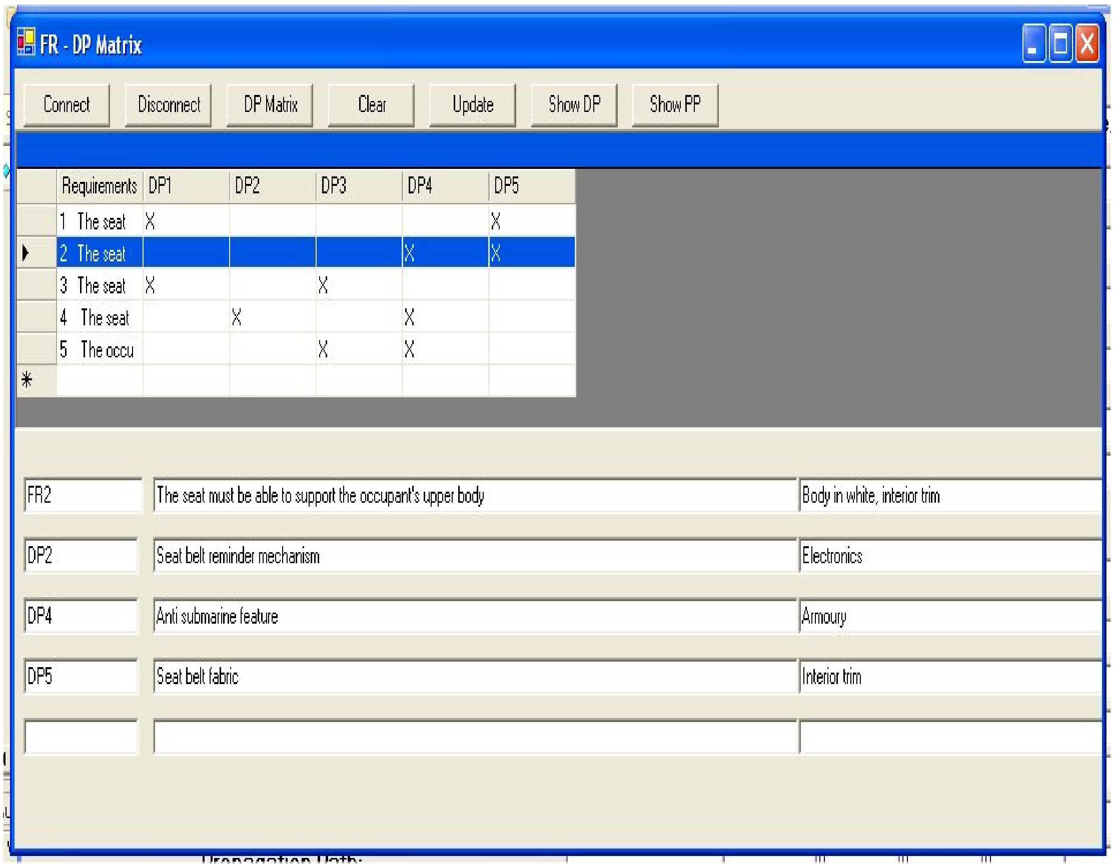


Figure 8-35: R-DP Matrix and Affected DPs.

Testing the system has demonstrated that the system fulfils its objective. The results from the tests are shown in Figure 8-34. These illustrate:

- How a requirement change is initiated by clicking on the R-R Matrix
- How the related DPs are generated in the Affected DPs
- How some of the identified list of DPs is selected
- How the cost drivers make up the cost of DPs
- How incurred cost of requirements change is generated

8.5.2 Validation of Software

The implementation of cost impact analysis methodology presented in this chapter is developed using VB.NET and MySQL. In other to determine the usability of the software this section presents validation strategy using the seating system case study. The software was validated by a target costing manager, a commercial project evaluator and three researchers to determine whether the software responded as intended in terms of cost impact analysis. The verification process was performed by allowing each participant to use the software and comment on the performance, accuracy, usability, relevance, completeness, business integration and observations on the software's behaviour.

The validation focused on the cost impact analysis of a requirement change. In order to verify whether the affected requirements, design parameters and cost impact are representative of the common cost impact analysis knowledge, the experts verified several scenarios. Six scenarios were conducted as shown in Table 8-3 to determine how the software responds to requirement change. For each scenario, the tests were carried out by varying suitable parameters.

Table 8-3: Experiment Plan

Scenarios	Scenario Name	Parameters
1	Change Origin	R3 The seat must be able to support the occupant's arm
2	Propagation Path (Affected Requirements)	R1 The seat must be able to support the occupant's lower body, R3 The seat must be able to support the occupant's arm and R5 The seat height must be adjustable
3	Affected Design Parameters	DP1 Seat heating mechanism and DP4 Anti-submarine feature
4	Selected Design Parameters	DP1 Seat heating mechanism, DP3 Seat belt bracket, DP4 Anti-submarine feature and DP5 Seat belt fabric
5	Cost Drivers Affected	Raw Materials, Labour, Bought out items and Tooling
6	Incurred Cost	€ 9.50

The validation of the software took 1 hour 30 minutes; 20 minutes for PowerPoint presentation, 50 minutes for demonstration of the software and 20 minutes for feedback through questionnaires.

Selection of Participants

A random selection of participants was made to reflect varied work group as illustrated in Table 8-4. In order to reduce bias the participants were asked not to include their names on the questionnaire. This allowed the researcher to make an objective analysis of the feedbacks from the participants.

Table 8-4: Participants Profile

Job Title	Sector	Years of Experience
Target Costing Manager	Automotive	26
Researcher	Lean Manufacturing	3
Commercial Project Evaluator	Aerospace	30
Researcher	Knowledge Management	2
Researcher	Media	15

Presentation

A twenty minutes PowerPoint presentation was conducted to familiarise the participants with the overall project (CIAM). Particular emphasis was made to the cost estimation of requirement changes. The software development process was mentioned; this involved an explanation of the analysis, design and implementation of the prototype system.

Hands on Demonstration

A 50 minutes hands-on demonstration of the prototype system was conducted. This gave the participant a first hand opportunity to understand how the system works. The participants were then allowed to simulate changes and generate results.

Questionnaires

The feedback was elicited through questionnaire, as illustrated in Appendix H. The questionnaire highlighted the validation of the system from the following perspectives:

- Performance
  - o Does the software perform cost impact analysis as expected (question 5)?
- Accuracy
  - o Are the results representatives of common cost impact analysis results (question 6 and 7)?
- Usability
  - o Is the software user friendly and easy to use (question 8 and 9)?
- Relevance
  - o Is the approach adopted by the software relevant to the application domain (question 10)?
- Completeness
  - o Does the methodology implementation in the software complete captures requirement change scenarios (question 11)?
- Integration into business
  - o How easy does the participants thick the software can be integrated into existing system (question 12)?
- Observations
  - o Any other observations and comments (question13 and 14)?

Table 8-5: Ranking of Questionnaire

Description	Questions	Ranking
Respondent Profile	1--4	2
Software System Validation	5--12	6
General Observations	13--14	2

Table 8-5 illustrates the relevance of the questionnaire to the software validation process. The respondent profile shows that the participants are relevant to the validation process. The software system validation is the most important set of questions in the questionnaire and show that the software is fit for the intended purpose. Finally, general observations allowed the participants to include any other issues the questionnaire does not address, thereby reducing bias from the researcher.

Summary of Validation

The summary of answers to the questionnaires, the questions are numbered and in bold letter:

1. Job Title Main role and years of experience
General Comments: The experience of participants ranged from 0 to 26 years, in different environment as depicted in figure 8-1.

2. Was the above experiences acquired from more than one organization?
General Comments: Some of the participants had gained there experience in one or more organisation. This allowed the participants to have more than one industrial perspective on the prototype.

3. Approximately how many times are you involved in cost assessment of requirement changes (daily, weekly monthly)?
General Comments: The frequency of participant's involvement in cost assessment of requirement changes was varied; none, weekly, monthly and quarterly.

4. How would you define cost impact analysis?
General Comments: Cost impact analysis was defined generally as the assessment of the cost of a design requirement change.

5. Does the software perform cost impact analysis of requirement changes as you would expect?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2					√	
3					√	
4					√	
5						√

General Comments: All of the participants agreed that the software performed cost impact analysis as expected. However, one participant was not certain if the software fits OEM/Supplier negotiations on commercial issues.

6. Do you agree with the approach to cost impact analysis?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2					√	
3					√	
4					√	
5					√	

General Comments: All participants agreed with the approach to cost impact analysis. However, some also mentioned that the approach considers effect of requirement changes on other related systems.

7. Do you agree with the results of the software?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2				√		
3				√		
4					√	
5					√	

General Comments: All participants agreed with the results from the software. However, one participant raised concern about the degree of changes in real life situations. Another participant mentioned that the tool demonstrated integration with database; the tool provides security and is easily accessible to the intended users.

8. Is the software easy to use?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2					√	
3			√			
4						√
5					√	

General Comments: Most agreed that the tool was easy to use and navigate through the windows. However, one participant argued that the tool was not clear to him and he believes the tool needs some improvement in its layout.

9. Is the software easy to understand?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2					√	
3			√			
4						√
5						√

General Comments: Again most of the participant agreed that the tool was user friendly. However, one participant disagreed with out any reason. Others espouse that the software was very clear, used standard software application features, was logical, provided an initial overview of cost impact analysis and was developed with consideration for the intended users.

10. Would you consider the software to be relevant to the automotive organization?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2					√	
3			√			
4			√			
5						√

General Comments: Most participants agreed that the methodology is relevant to the automotive industry. One participant added that the tool can be relevant in other manufacturing industries.

11. Does the software completely capture all possible scenarios of requirement changes?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1					√	
2				√		
3			√			
4			√			
5					√	

General Comments: Most participants agreed that the tool capture some scenarios of requirement changes, highlighting areas of the tool limitations such as tooling design and investment

12.Do you think the software can be easily integrated into your current business philosophy, or (any business philosophy)?

Respondents	Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1						√
2		√				
3					√	
4						√
5					√	

General Comments: Most agreed that the tool can be easily integrated into their current business philosophy. However, it was mentioned that system integration is a difficult task. Other mentioned that ripple effect propagation is a phenomenon common in other industries as well and that with a few modification and adjustments the tool could be used in other sections.

13. What are your general observations relative to the proposed benefits of the software?

General Comments:

The observations of participant in relation to the proposed benefits are:

- The tool will aid decision making process, feasibility study and understanding of the links of changes
- The tool will provide early visibility of design change during concept/design phases
- The tool shows what parameters to consider during cost impact analysis
- The tool demonstrates a very good business judgemental tool.
- Cost of requirements changes can help business to adjust parameters during design phase
- The tool clearly illustrates the cost associated with requirements changes
- The tool is easy to use and understand

14. Other comments

General Comments:

- The software is quite powerful, yet flexible
- I am positive that it has good potential and will be beneficial to the automotive industry
- It presents a logical approach to cost impact analysis and the methodology is easily understandable

The participants verified whether the combination of impact analysis for a given requirement change and the cost assessment of the change corresponds to their understanding of the problem. This indicated that the participants agree that the software behaves as expected, and there is no major unexpected trend in the software behaviour.

Most of the software discrepancies are related to process knowledge not accounted for in the software. The questionnaire used is shown in Appendix H. For example, participant 2 disagreed with question 12 commenting that system's integration is a difficult subject area and was not sure. Participant 3 disagreed with questions 8, 9, 10, and 11. The disagreement was due to clarity of the interfaces and the fact that participant 3 has no experience in the automotive industry. Participant 4 disagreed with questions 10 and 11 since he does not work in the automotive industry and is a novice to requirement change management concept.

Since the participants found no major discrepancies with the software, therefore no changes were made to the software. This level of consistency was considered suitable for the thesis. The software is therefore validated for cost impact analysis of requirement change problems. Although, one of the participants also mentioned that the tool is self explanatory, however, the tool will benefit from having help facilities. It was also mentioned that the robustness of the software needs to be improved, nonetheless it was agreed that this could be a focus of the next release of the software.

The feedbacks from the validation session are discussed in the future enhancement section. This will form a platform for additional features into the next release of the system.

8.6 Deployment and Maintenance

8.6.1 Deployment

The deployment stage discusses what is required in order to run the system and deliver the software to the end user. The software and instructions are on the CD labelled "CIAM Version 1.0"

8.6.2 System Requirements

2.80 GHz CUP

1 Gigabit hard disk space

512 RAM

VB.Net 2003

MySQL 1.4

8.6.3 Maintenance

One of the most challenging activities in implementation and automation is maintenance. Since there are separate databases for OEM and Supplier each organisation will have to maintain there database separately, however OEM and Suppliers using the system will have to inform each other of updates to the database. Implementation of database replication is a possible solution to consistency of databases.

Maintaining the software will be a joint activity between OEM and Suppliers as changes to the system will affect both parties. Changes to code relating to the OEM interfaces will need to be driven by the OEM, while changes to the Supplier interface will need to be driven by the Suppliers.

Maintaining a software system is a complex activity that involves the following:

- Constant upgrade of both software and hardware to meet up with latest technologies
- Training of staff in the use of the software
- Improvement of this first version (CIAM version 1.0) with enhanced features
- Testing of the system in the company environment and observing results with the aim of making modification in the system
- Employing a resident programmer to maintain and implement future enhancements to the code.

8.6.4 Future Enhancement

The tool could be further enhanced by adding help facilities, this could be text and presentation slides. Another enhancement could be the addition of images to illustrate systems of a mechanical product.

Currently querying the database requires some knowledge of SQL. In future it will be more beneficial to have a more interactive query form that will only require the users to click on tables of interest.

Database synchronisation for selected tables, for example the requirements are the responsibility of the OEM. A better approach to the implementation of the database is to copy OEM requirements table in the OEM database to the supplier requirements table in the supplier database.

In order to improve robustness of the prototype, the rule will need to be automated. A possible solution is to input the rules in the database and present users with the option of customising the rules. This will facilitate reuse of the system for other automotive components. Similarly the time rules and the external cost impact analysis rules will need to be implemented.

Due to the complexity of the enhancement mentioned above, especially the implementation of rules and the ability of the system to be reusable for other system. The researcher estimates that it will take two experienced VB.NET/SQL software developers eight months to fully implement the software system in order for it to be market ready:

- Two months for analysis
- Two months for design
- Three months for coding
- One month for testing and deployment

8.7 Key Observations

The objective of the prototype is to demonstrate that the methodologies developed in chapter 5 and chapter 6 can be conceptualised. VB.NET and MySQL have been used to implement the application and database respectively. Finally, key observations are explained:

- The system has use conventional methods such as matrixes, cost drivers and rules to generate propagation path and incurred cost.
- The system is a standalone system with the capability of being integrated to other systems through clearly defined interface.
- The CIAM system in particular has interface with two other programs developed for the e-RM project.
- The proposed system can be used by OEMs and suppliers for making project decisions.
- Within the OEM organisation, project Managers can use the system when approving change requests.
- Within the supplier organisation the system will aid managers in the assessment of the feasibility of a proposed change.
- The system will reduce rework time since there will be visibility of interconnectivity between elements of the product.
- Design engineers will also be able to assess the possibility of subsystem interrelationships before detailed design phase.

8.8 Summary

This chapter has presented the prototype software that implements CIAM. The software was validated by five participants. The software has fulfilled its development purpose. The system determines the cost impact of a requirement change by combining the impact analysis with rule based cost estimation technique. This system is the first of its kind, hence version 1.0. Subsequent versions will feature more capabilities. It is a worth while effort to develop a system that integrates the OEM and its suppliers for mutual business benefits. The user interfaces for both OEM and Tier 1 Supplier has been presented. The database architecture is also discussed.

The next section discusses the research contributions, the research limitations, future research direction and the research conclusion.

9 DISCUSSION AND CONCLUSIONS

9.1 Introduction

The relevant data extraction methodology (REXTRAM) in chapter 5 and cost impact analysis methodology (CIAM) in chapter 6 were the culmination of the literature review in chapter 2 and the industrial observations in chapter 4. The gaps in academic literature and industrial sectors have been captured in the literature review section and the AS-IS (current practice) section respectively. Hence, the need for a cost impact analysis methodology.

In order to explore the usability and generality of CIAM and REXTRAM, a further case study is developed and applied in chapter 7. The validation provides a base for discussing both the validity of the prototype architecture, and the conformance of the cost impact analysis methodology to the user requirements. This chapter discusses the research findings against the research aim and objectives. The key observations from this research are clarified and contribution to knowledge is discussed. Concluding remarks are presented and finally the direction for future research is considered.

Chapter Aim:

To discuss and conclude the implications of the research findings established in this thesis.

9.2 Discussion

The methodologies applied in this research follow a structured approach, which pursues the cost estimation of requirement changes within the automotive industry with parallel validation through case studies in the industrial environment.

The first methodology REXTRAM maps requirements to requirements, requirements to design parameters and finally design parameters to design parameters in order to make visible the relationship (R/R, R/DP and DP/DP) between them. An iterative flowchart was created to capture the steps required to conduct requirements extraction from design specification documents, as shown in Figure 5-1. From the interpretation of interview transcript, two categories of changes were identified: constraints changing on requirements and constraints changing on design parameters, as illustrated in section 5.4.2.

The second methodology CIAM, estimates the cost of design requirement changes. The methodology aims to improve the process of assessing the incurred cost of making a design requirement change. A second flowchart was developed to capture the steps required to conduct cost impact analysis for design requirement changes, as shown in Figure 6-2. The application of CIAM to mechanical product within the automotive industry has led to a better understanding of the relationships between the requirement, design parameters and their constraints.

The flowcharts have been refined through an iterative process, as a result of feedback from experts. The final methodologies were validated with cost estimator and design engineers. A design model was developed to map the internal cost impact analysis to a prototype system; the system allows reuse of the captured knowledge. Reuse is facilitated by a series of data entry interfaces, which allows the user to input relevant data into the system and use the inputs for many requirement change scenarios. An application prototype has been developed in VB.NET and MySQL

The main strength of the research is that it provides

- A unique opportunity to learn how requirements and design parameters within a system interacts.
- How requirements and design parameters can be used to determine incurred cost of proposed changes.
- How product descriptions can be used to create cost estimation rules.

A major issue with any research is bias; the researcher reduced both respondent bias and researcher bias by:

1) Prolonged involvement with the client organisation (sponsoring companies). The author visited the sponsoring organisation at least once a month in order to have a good understanding of the OEM and Tier 1 Supplier operations.
2) Triangulation i.e. using more than one source (literature review and industrial observation) to investigate the problems identified in this research. Detailed literature review was conducted and a comprehensive model of the current practice was developed.
3) Audit trial i.e. the researcher kept every record of work carried out. Records were kept as soft copies, these records comprised of emails, printed documents, etc.
4) Peer debriefing i.e. working extensively with industrial and academic supervisors to collate ideas after meetings and workshops. Each meeting was transcribed and sent to all participants for clarification.

An attempt has been made in this research to keep the methodologies as generic as possible. However, as with any other research, the methodologies have some limitations. The weakness of the methodologies is their applicability to other domains. This is because time and resources are limited and therefore it has not been tested widely in other mechanical sectors.

9.2.1 Literature Review

This research has reviewed common concepts in cost estimation and impact analysis. It is observed that the cost estimation of design requirement changes is ad-hoc, error prone and time consuming, and there is no significant literature on cost estimation of requirement changes, but rather on cost estimation and impact analysis as separate research topics. The problem of CIAM in the automotive industry is both a complex and knowledge intensive task; it relies on the expertise of the cost estimators and design engineers.

The research has also looked at other research groups in cost estimation and impact analysis in varied sectors such as software, aerospace, construction, health, and marine. A common theme across the sectors looked at is that impact analysis practice needs to decompose the domain (system) into requirements and solutions. Therefore, allowing analysts to establish relationships between requirement and solution.

It is observed that research in these areas mainly focused on automating the cost estimation process and formalising impact analysis process. Hence, there is a need to provide cost impact analysis methodology for mechanical design systems within the automotive industry, since there has been no significant research reported in this area. External cost impact analysis for the main systems of a vehicle has also been created.

To address the problem of cost impact analysis within the automotive industry, this research has examined the dominant techniques in cost estimation, impact analysis and their limitations. However, observation shows that the dominant techniques do not discuss the transformation from impact analysis to cost estimation. To address these problems, the research has reviewed current approaches of cost estimation and impact analysis in various sectors. The review of literature suggests that there is limited research in these areas.

There are several publications under the headings 'requirements management', 'requirement changes' and 'impact analysis' in the literature, but only a handful address the issue of cost impact analysis and extraction of relevant requirements and design parameters as described in this thesis. It is observed that there is not much research addressing the need to formalise the cost estimation process required for design requirement changes.

Expert Judgement vs. Structured Process

Expert judgement (EJ) is used throughout this research this leads to the questions:

- To what degree is expert judgement or automation required in methodology development?
- How could one trade-off between expert judgement and automation?

Several authors argue that EJ is subjective and biased (chapter 2). However, expert judgement is an integral pert of any methodology development, although the aim of developing a methodology in the first place is to automate a process. For example an expert judgement approach can be automated.

This research has automated the cost impact analysis for requirement changes using EJ and rule based approach. However, it must be noted that the automation was achieved through expert judgement. On this note it is suffice to argue that any robust methodology will combine the use of expert judgement (to provide domain knowledge) and automation (to increase robustness).

The development and use of logically derived methodology cannot and does not remove the subjective element of cost estimating (Curran, 2004; Davis, 2001; Martinsons, 1995). In fact, both the development and use of cost models is a subjective process that depends on the use of expert judgement (Duverlie, 1999; Wang and Stockton, 2001).

Current methods for integrating expert judgement focus on the use of artificial intelligence techniques and models. These do not remove the need for expert judgement both in terms of using the models and interpreting the results. Little attempt is made to capture rationale as an estimate is generated (Rush, 2002).

9.2.2 Analysis of Requirement Management: Case Study

A current practice model has been developed to capture the cost estimation of requirement change process. Flowcharts were created and validated in a collaboration workshop with experts from OEM and Tier 1 Supplier. The workshop facilitated the identification of bottlenecks in the current ad-hoc process of determining incurred cost of design requirement changes. The workshop consisted of the SDT (simultaneous development team) members. SDT is made up of design engineers, development engineers, accounts, production, materials, purchasing QA and test engineers. The results were also validated in publications and peer review.

9.2.3 Developing a Relevant Data Extraction Methodology (REXTRAM) for Cost Impact Analysis Methodology

The development of REXTRAM was based on literature review and case study criteria. This section discusses REXTRAM, while the next section discusses CIAM.

REXTRAM identifies six types of relevant data: subsystems, requirements, constraints on requirements, design parameters, constraints on design parameters and external impacts. It presents guidelines for the extraction of the various types of relevant data from a mirage of design documents. In addition, it presents logical activities required to analyse design documents. REXTRAM is used to extract high-level and low-level requirements for the cost impact analysis methodology (chapter 6). Flowchart is used to represent the activities required to extract relevant data from design document. The ability to structure and logically define relevant data from design documents is what distinguishes REXTRAM from other extraction techniques described in literature.

REXTRAM gives the experts the chance to express themselves within a structured approach by allowing dialogues with semi-structured questions. By providing flexibility within a structured approach, REXTRAM makes it easier for experts to follow and relate to their requirement change cost estimation process. The flexibility within the structured approach also permits some of the natural "lateral thinking" and implicit knowledge of change request, to be established.

The seating system diagram in chapter 5 identifies several components in the system. The R/R matrix (in chapter 5) identifies several components in the system; their interactions are depicted. Such interactions come about due to a number of effects, including tooling impact and material impact, among others. For example, the backrest and the seat cushion are functionally coupled via the hip-point position between them. The design of the backrest is influenced by the position of the hip-point and the position of the seat cushion. Both the backrest and the seat cushion are also closely coupled with the rail via the amount of weight the seat should be able to hold.

The weight distribution on the cushion is also dependent on the weight capacity of the backrest. The backrest and the cushion are also directly coupled because of the travel distance of the slider. The movement of the cushion influences the movement of the backrest.

Complete uncoupled relationships may not be easily accomplished in our case since the initial design is already been agreed and the designers are not following the steps of axiomatic design. Dependency exists among Rs. Designs where more than one DP satisfies Rs are acceptable, as long as the design matrix [A] is a triangular, that is, the non-zero elements occur in a triangular pattern either about or below the diagonal.

The R/R (in chapter 5) matrix depicts uncoupled relationships, since the matrix is diagonally symmetrical i.e. R1 → R2 == R2 → R1. In a coupled relationship R1 → R2 <> R2 → R, this indicates that the effect of changing R1 on R2 is not the same as the effect changing R2 will have on R1.

In Table 5-11, it can be seen that R5 → R1, R5 – The seat height must be adjustable is strongly linked to R1 – The seat must be able to support the occupant's lower body and vice versa, this is an example of a decoupled relationship.

Uncoupled relationships exist between R3 and R7, R3 – The seat must be able to support the occupant's arm and R7 – The seat's upper body support angle must be adjustable. This is also true for the inverse R7 → R3.

R/DP matrix (in chapter 5) further reiterates the decouple relationships that exist in the car seat system. For example, R3 – The seat must be able to support the occupant's arm, is satisfied by 3 DPs:

1. DP29 -- Front armrest frame right/left
2. DP34 – Front armrest right/left fabric
3. DP38 – Front armrest right/left foam

This methodology assumes the coordination between OEM and Tier 1 supplier exist, when defining the product architecture and organizing the development teams. These interactions between requirements and design parameters demand a high degree of coordination between OEM and Tier 1 Supplier engineers or development teams related to the seat system components.

The main strength of REXTRAM is the ability to generate requirement and design parameters for cost impact analysis of requirement changes. This enables the understanding and sharing of product knowledge between cost estimators and design engineers. The main weakness of REXTRAM is that it is time consuming to collect and analyse documents. The successful use of REXTRAM depends on creating effective relationship between OEM and Tier 1 Suppliers. The methodology is easy to implement and communicate. It was also observed that REXTRAM is easily understood by novice and experts.

REXTRAM has been applied to two automotive case studies by the author at Cranfield University. The results of the application have been validated in terms of usability and usefulness. All indications from the application of the case studies suggested that the methodology has been generally satisfactory, though there is room for improvement. It has been possible to generate data for external and internal cost impact analysis of requirement changes in two case studies using flowcharts.

9.2.4 Developing a Cost Impact Analysis Methodology (CIAM) for Design Requirement Change Management

REXTRAM provides data for the population of three types of matrix 1) requirements/requirements, 2) requirements/design parameter and 3) design parameter/design parameter matrixes. CIAM identifies two types of changes: 1) Constraints changing on requirements, and 2) Constraints changing on design parameters.

For constraints changing on requirements, requirements/requirements and requirements/design parameter matrix are used. The first step is to identify the affected requirements from the requirement/requirement matrix. The next step is to identify associated design parameters from requirements /design parameter matrix.

For constraints changing on design parameters the design parameter/design parameter matrix is used to generate affected design parameters list. The resulting design parameters form the foundation for cost assessment. Systems cost drivers are identified and what-if rules are created to assign cash value to each design parameter. The cumulative value of the affected design parameters is the incurred cost of implementing a proposed change.

This research has demonstrated that it is possible to structure the cost estimation process of requirement changes. CIAM procedural flowcharts identified the activities required to qualitatively assess the incurred cost of implementing a requirement change in worst case scenario.

This thesis presents application of CIAM on two case studies from the automotive industry (the same case studies used in REXTRAM). A generic cost impact analysis methodology for the cost estimation of requirement changes for mechanical automotive systems has been developed. The main strengths of CIAM are the ability to logically create impact analysis matrixes, cost estimation rules, the ability to establish logical relationships between requirements and design parameters of a mechanical system within the automotive industry.

CIAM has been validated in two case studies, two scenarios for each, on two types of design requirement changes. The case studies have shown that CIAM accurately captured the relationships between requirements and cost estimation rules. Although CIAM has not been applied in other industries, it is expected that the results will be similar. CIAM reflects cost estimators and design engineers reasoning process with regards to cost estimation of requirement changes. The approach adopted for validation was repeated "walk through" paper simulation with domain experts for the two case studies. The methodology was validated for accuracy, reduction in incurred cost determination time and significant elimination oversight in terms of cost impact assessment. Where necessary, feedback from the walk-through tests was used to iteratively modify and extend CIAM.

A benefit from developing the methodology this way, is that it provides visibility between the OEM and their Tier 1 Suppliers, making it easy to assess the impact of proposed changes. CIAM is reusable and adaptable for mechanical systems, i.e. once a set of data has been extracted for a system, the data can be used for all requirement changes relating to the system. It is intuitively clear from CIAM in the research that cost impact analysis of requirement changes is not specific to the automotive industry.

Interpretation played an imperative role in the methodology development. The interpretation of data elicited requires a deep understanding of problems in the domain. The interpretation was in two stages, first from interview transcripts, and then from in-house documentation. This creates deeper understanding of the problem and solution for the researcher. Industrial collaborators were able to unveil some hidden issues concerning their requirement change procedures. The interpretation process is subjective and prone to errors, since interpretation is the process of analysing, verbal data obtained from the experts in order to explain their reasoning process.

To reduce the bias, every session involving the application of CIAM was recorded on audiotape with the permission of the interviewees. Transcripts from the interviews were checked with experts to validate data used in the development of CIAM and REXTRAM. The level of generalisation is limited due to the use of only case studies from the automotive environment. The researcher would have preferred to conduct a greater number of case studies; however, this was not possible within the scope of the research. Validating the methodologies in comparable domain can reduce the bias and its effect.

Cost estimation rules were created from the system cost drivers and system components. The cost drivers are those factors that can significantly influence the cost estimation process, for example, tooling labour and raw material. These rules create a logical transition from the impact analysis phase to the cost assessment phase. The rules associate a cash value to each design parameter depending on other factors, such as current capacity of tool, required capacity, purchase region, development phase and size of part affected by change.

The reliability of a valid methodology significantly depends on the validation by domain experts. A rigorous attempt was made in this research to validate the methodology by expert judgement. A domain expert using paper based simulation method validated the methodology in section 7.7.1. The validation process took two days and consisted of three stages. Stage one and stage two on the first day and stage three on the second day.

The first stage provided a brief introduction of the research. The description of the terminologies used to define cost estimation of requirement changes was also provided. The second stage provided additional explanation and comments about activities within the flowcharts. The third stage described a step-by-step paper simulation of the two case studies on constraints changing on requirements and on constraints changing on design parameters.

The reliability of results obtained in paper simulation is subjective, but rigorous. These results are expressed in qualitative terms. The results were deemed good by the domain expert. Especially for highlighting the complexity of the domain and establishing relationship between requirement, design parameters and cost rules. In addition, it reveals some issues that were not captured in the flowchart such as warranty and product recall issues. The problems encountered with the results were the depth of analysis required to implement a change request and to conduct cost assessment.

The difficulties in getting access to experts always present a challenge. The difficulty is mainly because expert time is very expensive and their workload does not allow too many external meetings.

Internal cost impact analysis requires only the collaboration between an OEM and one of its Tier 1 Supplier. For example, a car manufacturer (OEM) and the seat provider (Tier 1 Supplier). While external cost impact analysis requires a domain expert in other systems (e.g. Interior trim system, body-in-white system, dashboard system, etc) to form a comprehensive and detail analysis of the impact a changes to one systems (seat) will have on other related systems (Interior trim and body-in-white). However, the OEM can provide enough information to make an informed decision on the effects of one system on other systems.

It was necessary to persuade and negotiate time and location to gain access to experts. The researcher had to be flexible concerning timing and location. The researcher collected data and validated his interpretations. The difficulties in getting access to experts delayed the validation process. It is observed that experts in the automotive environments easily understood CIAM and REXTRAM.

9.2.5 Developing a Prototype System for Cost Impact Analysis Methodology

This research has developed UML architecture for the implementation of CIAM for the automotive industry. The architecture covers two-stage transformation process, characterised by interrelated decisions that have to be made during the design process. The research has mapped the UML model steps to operations in the software programming language. Three application-programming environments were considered, CORBA, J2EE and VB.NET. All three were evaluated for suitability, price of licence, ease of use, availability and portability of the software. Finally, VB.NET was chosen as the preferred programming environment. This decision was based on commercialisation potentials and migration of industrial collaborators to Microsoft.NET environment.

One of the objectives of the sponsor company is to integrate CIAM with other systems in the future. VB.NET environment is well supported by Microsoft and has many online user groups. VB.NET is object oriented; it facilitates reuse and is extendible. The general structure of the application model is defined in the architectural design model, which specifies systems and subsystems decomposition. MySQL was chosen as the preferred database management system (DBMS). MySQL is a free open source application; it is well supported and has many online user groups.

The prototype design follows object oriented programming environment, which is the prevailing paradigm in software engineering. Given the object oriented nature of the UML design, mapping CIAM steps to an object oriented software environment is simplified. The prototype is organised in logical tab windows. These tab windows follow a logical pattern of activities required from CIAM.

The main benefit of object-oriented design is that it facilitates the reuse of software components, and it is easy to maintain the classes. The main system architecture consists of a programming language (VB.NET) and a database management system (MySQL).

The issue of maintenance is an important consideration for the development of CIAM, as case study implementation can be reused for other similar product. For example, a case study implementation of the car driver seat can be reused for the assistant seat. It is important that an expert is available to maintain and preserve the structure of the software system and database, trace any omission or inconsistency. This will ensure maintenance is simplified and future functionality extension can be facilitated.

9.3 Research Contribution

The main contribution to academic knowledge is the development of a generic methodology to facilitate the cost impact analysis in a collaborative (OEM/Tier 1 Supplier) environment, for mechanical automotive systems. This methodology is based on product structure decomposition. Ripple effect propagation paths are determined by examining the requirements and design parameters of a system. Cost analysis is assessed by creating rules using product cost drivers, development stage and design parameters. To the knowledge of the researcher, no previous studies have combined impact analysis and cost analysis to determine incurred (delta) cost. The following section outlines the research reported in this thesis:

- REXTRAM presents a novel approach to extracting requirements, design parameters and constraints from design documents and experts.
- REXTRAM presents a ranking of extent of impact when two requirements are related
- REXTRAM identifies a unique set of stop criteria to manage propagation when requirements and design parameters are propagating endlessly.
- REXTRAM identifies three types of matrixes; requirements/requirements, requirements/design parameters and finally design parameters/design parameters.

- CIAM identifies two types of changes: requirements changing on constraints and design parameters changing on constraints.
- CIAM identifies business drivers i.e. cost and time driver. To aid the cost estimation of requirement changes.
- CIAM distinguish between internal impact analysis and external
- CIAM and REXTRAM offer reusability of rules and matrixes. Once the methodologies have been applied to a system. The components of the methodology such as the matrixes, the cost rules, product structure, cost drivers and development stages are reusable for products in the same product family. For example, some of the requirements and design parameters for the driver seat are applicable to the rear seats. The product structure, cost drivers and development stages are the same for driver, front passenger and rear seats.
- The methodologies are capable of dealing with coupled design. Coupling occurs when requirements are intricately link.

9.4 Application of REXTRAM and CIAM in Industry

The activities required to apply REXTRAM and CIAM is performed by OEM and Tier 1 Supplier. Table 9-1 presents a responsibility assignment table, which illustrates activities performed by the OEM, activities performed by the Supplier and activities performed by both OEM and Supplier. For example, the case study selection is initiated by the OEM. The OEM needs to get a supplier that is willing to share cost impact analysis data. The Supplier will need to perform the domain analysis activity, since the supplier holds the manufacturing knowledge.

Table 9-1: Responsibility Assignment

Activities	OEM	Supplier
REXTRAM		
Case study selection	√	
Domain Analysis		√
Identification of relevant Document		√
Identification of relevant text		√
Validation of requirements	√	
Validation of design parameters	√	
Identification of change type	√	

Creation of repository		√
Creation of matrix	√	√
Internal CIAM		
Analysis of Change request	√	
Generation of propagation path	√	√
Validation of impact analysis results	√	√
Identification of business drivers	√	√
Identification of system component		√
Creation of cost and time matrix (how many rules)		√
Validation of rules		√
Impact analysis summary	√	√
External CIAM		
Determination of change origin	√	
External propagation path	√	
Creation of external cost estimation rules	√	
Determination of incurred cost on subsystems	√	
External impact analysis summary	√	

Table 9-1 is divided into three sets of activities: 1) REXTRAM activities, 2) CIAM activities and 3) External cost impact analysis activities. The ticks indicate which activity is performed by whom. Some activities are performed by both OEM and Supplier. Activities performed by both OEM and Supplier will require close coordination between the both parties.

9.5 Business Impact Analysis for OEM/Tier 1 Supplier

The main industrial contribution is to facilitate improvements in the impact analysis and cost estimation process of requirement changes of mechanical systems within the automotive industry. Similar knowledge can be captured about other systems, Table 6-4 shows some other system within a car that can be used, e.g. the break system, the dashboard system, etc. The case study validation in chapter 7 demonstrates the applicability of REXTRAM and CIAM to other systems. The methodologies can also be applied to other sector, such as the aerospace industry. Aerospace products can be divided into systems in a similar fashion as the automotive sector. Although a thorough investigation of the applicability will need to be conducted before any possible benefits could be discussed.

The methodologies can be applied to subsystems (e.g. headrest) of a system (e.g. seat). Indeed this research was conducted, but the results indicated that requirements that are related to multiple subsystems were not adequately analysed. For example, change seat cushion shape (an example of a change to seat in Table 6-5) which affects requirements:

- R1 – The seat must be able to support the occupant’s lower body
- R5 – The seat height must be adjustable
- R6 – The seat's lower body support angle must be adjustable
- R9 – The occupant must be able to adjust the temperature of the seat

The requirements above in turn affect other requirements in other subsystem. The complexity increases as subsystem are treated individually; fabric colour change is one of such issue. A change to the colour of the headrest will affect the colour of the rest of the seat, which in turn will affect the interior trim (an external system to the seat). A further complication was the definition of external impact, i.e. if the methodologies are applied to a subsystem e.g. headrest, the backrest and cushion will be external systems to the headrest. Moreover, the industrial collaborator mentioned that each system is treated as a unit; this assertion was also confirmed by the independent expert.

Within the context of this research a system is a pre-assembled part of a car, usually this part is supplier to the OEM by Tier 1 Supplier, while a subsystem is a further decomposition of the pre-assembled part from the Tier one supplier. For example, the car seat is a system, while the headrest, backrest, armrest are examples of subsystem. Although some of the subsystems are further out sourced to Tier 2 Supplier. Tier 2 Suppliers may be able to benefit from the internal cost impact analysis point of view, however external impact analysis will need to be investigated thoroughly before a constructive analysis can be done. It must be emphasised that the successful application of the methodology requires a good relationship between OEM and Tier 1 Suppliers.

9.6 Software System Maintenance

The prototype tool can be used for impact analysis for changes on car seats, however cost estimation will some minor modifications to the code. The rules will pose a major challenge to any attempt to reuse the system. One possible solution is to have a database driven rules implementation, in this case the rules will be entered into a database table and manipulated to assign appropriate value to the affected design parameters identified from a change scenario. An interface exists on the system for entering the business rules, these values are not used within the system.

Currently requirements and design parameters can be added or deleted from the system. Relationships between requirement and design parameters can also be modified. However the rules are hard coded due to the time and complexity involved in analysing and designing the code to manipulate and assign value to the different change scenarios.

The researcher estimates that it will take two experienced software developers eight months to fully implement the software system in order for it to be market ready:

- Two months for analysis
- Two months for design
- Three months for coding
- One month for testing and deployment

9.7 Conclusions

This research has achieved the main aim and all the objectives of developing a relevant data extraction methodology and a cost impact analysis methodology for mechanical systems in the automotive industry.

- This thesis has presented a review of techniques to manage cost estimation of requirement changes.

- The review of techniques for impact analysis and cost estimation has identified the need for improvement in cost estimation of requirement changes process for mechanical automotive systems.
- This research has also identified lack of a structured methodology in determining incurred cost of requirement changes, especially for hardware products.
- Design specifications do not necessarily articulate design requirements, design parameters and their constraints in a succinct and concise manner. Therefore, an extraction methodology (REXTRAM) has also been developed for the extraction of design requirements, corresponding design solutions, constraints and their mutual relationships from automotive design documents and experts.
- The novel cost impact analysis methodology developed in this research has two perspectives impact analysis and cost analysis at the specification stage with the level of information available with automotive OEMs.
- This research has developed a set of cost estimation and time estimation rules based on mechanical system business drivers, suitable for the specification stage.
- The research has shown that through iterative refinement, it is possible to extract requirements, design parameters and their constraints.
- These extractions can be used along with the rules to qualitatively assess the cost incurred on design requirement changes.
- The research has developed a prototype system for implementing cost impact analysis. To achieve this, a UML design model is developed; it mapped cost impact analysis steps to operations in an application programming language environment. This research has shown that it is possible to conceptualise cost impact analysis in an application programming language environment.

9.8 Research Limitations and Future Research Directions

Despite the advantages, the extraction process has some limitations in practice, especially in understanding what a requirement is as oppose to a requirement, this is a common misunderstanding amongst engineers. For example, 'the seat must be able to support an occupant's upper body' is a requirement. Requirements usually have no measurement in them; the measurement is actually the constraints. A requirement will be 'the seat must support a targeted population of 5th percentile female and 95th percentile male'. Car seat dimensions are specific for a target population constrained by appropriate anthropometric dimensional values, i.e. 5th percentile female and 95th percentile male.

Although this research identified interviewing and case study analysis as the two techniques for data collection, there are possibly other techniques, such as brainstorming which have not been considered. The researcher is conscious that more validation of CIAM and REXTRAM could have been achieved, but for lack of resources, this was impossible. It is acknowledged that lack of validating CIAM and REXTRAM in a wider domain may be seen as a limitation in a larger context. In summary, literature review shows a lack of structured process for the extraction of design requirements and design parameters for automotive systems at the early phase of product design.

The main limitation in the development of CIAM and REXTRAM is the role of bias and interpretation in analysing extracted data from experts. The approach used to identify relevant documents and extract data is susceptible to interpretation; this may be because it relies on experts opinions during data collection.

In this research, although a cost impact analysis methodology for mechanical design requirement changes within the automotive industry was successfully developed and implemented. It has not been possible to test the methodology in any other domain. For example, mechanical systems such as the seats, hydraulics, body panel in the Aerospace industry.

This research implements a methodology that establishes relationships between requirements and design parameters, and maps design parameters to cash value, in an appropriate application-programming environment. The limitation of developing the prototype in an application such as VB.NET and MySQL is the time and resources required in learning the language and justifying its benefits. The decision to use VB.NET and MySQL was guided by the migration of the Sponsor Company to

VB.NET. Therefore, the selection is not purely based on the technical merit of the application environment.

The validity of the results obtained in this research has been established. Nevertheless, further research could be conducted in the research topic domain. Indeed confidence in the result of CIAM and REXTRAM could be improved by applying other evaluation techniques, and comparing results and resources utilised. Future activities to develop the CIAM would have to address the following questions:

1. *How could the role of interpretation in CIAM and REXTRAM development be minimised?*

Addressing this question will require an understanding of the activities involved in the translation of data extracted through the use of REXTRAM. The process of developing CIAM using the results from REXTRAM has to be understood in terms of the role of requirements, design parameters, cost drivers and cost estimation rules. Essentially, the analysis of REXTRAM results and the development of CIAM from these results require structured interpretation. In order to minimise the role of interpretation, future research has to focus on areas where most interpretation takes place in translating relevant data. A template-based approach could be developed to guide the interpretation and therefore reduce bias.

2. *How can the application of CIAM and REXTRAM be made faster and suitable for other applications?*

The application of CIAM as a requirement change cost estimation process and REXTRAM as a data extraction process is a unique and novel approach. This research has generated two guidelines in the form of flowcharts for analysing documents and mapping the results from the analysed documents to cost rules. To reduce the time required for future application of REXTRAM and CIAM, the facilitator needs to acquire some knowledge from existing sources to partially populate the matrixes and cost rules, and then get the experts to fill in the gaps.

3. *How can the methodologies be made more generic?*

The methodologies developed in this research have been validated with case studies within automotive industry. Future work should focus on developing case studies in other domains. This way, the methodology can be more generic for wider application. To achieve this would require identifying a project dedicated to cost impact analysis of requirement changes, in order to gain deeper understanding of the domain. With more time and resources the methodology should be tested in other complex environment, such as aerospace and construction.

REFERENCES

Abbattista, F., Lanubile, F., Mastelloni, G. and Visaggio, G. (1994), "An Experiment on the Effect of Design Recording on Impact Analysis", *Proc. of the IEEE International Conference on Software Maintenance*, Victoria, Canada, September 1994, p. 253-259.

ACostE (2000), "A Glossary of Professional Terminology and Definitions" Published in The Association of Cost Engineers.

Agouridas, V., Baxter, J., McKay, A. and de Pennington, A. (2001), On Defining Product Requirements: A Case Study in the UK Health Care Sector Proceedings of DECT'01, 2001 ASME Design Engineering Technical Conferences, Pittsburgh, Pennsylvania, USA.

Ajila, S. A. (1995), "Software Maintenance : An Approach to impact Analysis of Objects Change", *International Journal of Software,* 25(10), p. 1155 – 1181.

Akao Y. (1990), "Quality function deployment: integrating customer requirements into product design". Cambridge, MA: Productivity Press.

Akin, Ö. and Özkaya, I. (2002), "Models of Design Requirement", *Sixth Design and Decision Support Systems in Architecture and Urban Planning - Part one: Architecture Proceedings Avegoor*, the Netherlands.

Almefelt, L., Andersson, F., Nilsson, P. and Malmqvist, J. (2003), "Exploring Requirements Management In The Automotive Industry", *International Conference On Engineering Design Iced 03*, Stockholm, August 19-21.

Andersson, F., Sutinen, K. and Malmqvist, J. (2003), "Product Model for Requirements and Design Concept Management: Representing Design Alternatives and Rationale", *Proceedings of INCOSE-2003*, Washington, USA.

Arnold, R. S. and Bohner, S. A. (1993), "Impact analysis -- towards a framework for comparison", *Proc. Conf. Software Maintenance, Montreal, Quebec, Canada*, p. 27-30.

Bae, S., Lee, J. M. and Chu, C. N. (2002), "Axiomatic Design of Automotive Suspension Systems", *CIRP Annals*, 51, p. 115-118.

Becker, B. and Wang, N. (2003), "An Engineering Requirements Management Method (ERMM)", *ASME 2003 Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Chicago*, Illinois, USA, 2-6 September.

Bennett, K. H. (1996), "Software evolution: past, present and future", *Information and Software Technology*, 39, p. 673-780.

Bjorner, D. (2002), "Domain Engineering "Upstream" from Requirements and Software Engineering Design".

Black, T. A., Fine, C. H. and Sachs, E. M. (1990), "A Method for Systems Design Using Precedence Relationships: An Application to Automotive Brake Systems" M.I.T Sloan School of Management, Cambridge.

Bohner, S. A. and Arnold, R. S. (1990), *Software Change Impact Analysis*, McGrawHill, New York.

Borzekowski, R. (2002), "Measuring the Cost Impact of Hospital Information Systems: 1987-1994" Board of Governors of the Federal Reserve System, Washington.

Brimson, J. A. (1998), "Feature Costing: Beyond ABC", *Journal of Cost Management*, 12(1), p. 6-12.

Bronsvoort, W. F. and Jansen, F. W. (1994), "Multi-view feature modelling for design and assembly", *Advances in Feature Based Manufacturing, Chapter 14*, p. 315-329.

Browning, T. R. (2001), "Applying the Design Structure Matrix to System Decomposition and Integration Problems: A Review and New Directions", *IEEE Transactions on Engineering Management*, 48(3), p. 292-306.

Bryman, A. (2001). *Social research methods*. Oxford University Press, Oxford.

Burns, R. (2000), *Introduction to research methods*, Sage Publications Limited, London.

CalISO (2000), "Comprehensive Market Redesign: Cost Impact Analysis" California Independent System Operator, State of California.

Catania, G. (1991), "Form-features for mechanical design and manufacturing", *Journal of Engineering Design*, 2(1), p. 21-43.

Cavalieri, S., Maccarrone, P. and Pinto, R. (2004), "Parametric vs. Neural Network Models for the Estimation of Production Costs: A Case Study in the

Automotive Industry", *International Journal of Production Economics*, 91(2), p. 165-177.

Chan, D. S. K. and Lewis, W. P. (2000), "The Integration of Manufacturing and Cost Information Into The Engineering Design Process", *International Journal of Production Research*, 38(17), p. 4413-4427.

Chen, L.-C. and Lin, L. (2002), "Optimization of product configuration design using functional requirements and constraints", *Research in Engineering Design*, 13, p. 167-182.

Chen, L.-H. and Weng, M.-C. (2003), "A Fuzzy Model for Exploiting Quality Function Deployment", *Journal of Mathematical and Computer Modelling*, 38, p. 559-570.

Churchill, R and Suprenant, C. F. (1983), “An investigation into the determinants of customer satisfaction”, Journal of *Marketing Research.* 19, 491-504 (1983).}

CIMdata, I. (2001), "Program Review of SAP's mySAP Product Lifecycle Management cPDm Program"

Clarkson, P. J., Simons, C. and Eckert, C. (2001), "Predicting Change Propagation in Complex Design", *Proceedings of DETC ’01 ASME 2001 Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Pittsburgh, Pennsylvania, USA, 9-12 September, p. 765-797.

Cleland-Huang, J., Chang, C. K., Javvaji, K., Hu, H., Sethi, G. and Xia, J. (2002), "Automating Speculative Queries through Event-based Requirements Traceability", *IEEE Joint Conference on Requirements Engineering , Essen, Germany*.

Cochran, D. and Vicente, A. (1996), "Axiomatic design of manufacturing systems", *MIT, Cambridge, Mass*.

Cochran, D. S., Chu, A., Linck, J. and Won, J. (2000), "Manufacturing System Design of Automotive Bumper Manufacturing", *Proceedings of The Third World Congress on Intelligent Manufacturing Processes and Systems*.

Cognition (2005) “Enterprise Cost Management”. Citing Internet resources (WWW document). http://www.cognition.us/products/ecm_proddesc.htm, (Date of Access September 30).

Cohen, T. and Fulton, R. E. (1998), "A Data Approach toTracking and Evaluating Engineering Changes", *ASME Design Engineering Technical Conferences,Proceedings of DETC'98, Atlanta*.

Cohen, T., Navathe, S. B. and Fulton, R. E. (2000), "C-FAR, Change Favorable Representation", *Computer-Aided Design*, 32, p. 321-338.

Collopy, P. D. and Curran, R. (2005), "The Challenge of Modeling Cost: The Problem", *1st International Conference on Innovation and Integration in Aerospace Sciences*, Queen's University Belfast, Northern Ireland, UK, 4-5 August.

Colmer, S. (2005), Developing a Cost Estimating Methodology for New Technology Intensive Products (MSc). Cranfield University, School of Industrial and Manufacturing Science. 160.

Colquhoun, G. J. and Baines, R. W. (1991), "A generic IDEF0 model of process planning", *International Journal of Production Research*, 29(11), p. 2239-2257.

Court, A. W., Culley, S. J. and McMahon, C. A. (1995), "Modelling the Information Access Methods of Engineering Designers", *7th International Conference on Design Theory and Methodology (DTM 95)*, Boston, MA, USA, 17-21 September 1995, p. 547-554.

Crozier, P. M., Guenov, M. D. and Buxton, I. D. (1994), "Concurrent Conceptual Design and Cost Estimating", *Transactions of 13th International Cost Engineering Congress, London*.

Curran, R., Rush, C., Roy, R. and Raghunathan, S. (2002), "Cost Estimating Practice in Aerospace: England and Northern Ireland", *Advances in Concurrent Engineering, CE2002*, p. 849-859.

Das, S. K. and Gami, S. (2004), "Expert rules for manufacturability analysis of misalignment defects during product design", *International Journal of Computer Integrated Manufacturing*, 17(1), 58-68.

Dauda, M., Roy, R. and Stephenson, D. J. (2005), "Development of a Cost Model for High Efficiency Deep Grinding (HEDG)", *The 3nd International Conference on Manufacturing Research (ICMR 2005) - Encouraging Applied Research in Industry*, Cranfield University, Bedfordshire, UK, 6-8 September.

Davis, M. (2001), “Adaptive AHP: a review of marketing applications with extensions”, European Journal of Marketing, 35(7/8), 872-893, ISBN 0309-0566.

Davis, P. C. (1994), "A Suggested Methodology for Estimating the Cost Impact of Changes to the Model Building Codes" NAHB Research Center, Upper Marlboro, Maryland.

Dorador, J. M. and Young, R. I. M. (2000), "Application of IDEF0, IDEF3 and UML methodologies in the creation of information models", *International Journal of Computer Integrated Manufacturing*, 13(5), p. 430-445.

Dori, D. (Ed.) (2002) *Object-Process Methodology - A Holistic Systems Paradigm*, Springer Verlag, Heidelberg, New York.

Duncan, M. (2001), *Sams Teach Yourself Visual Basic .NET in 21 Days*, Sams Publication, USA.

Duverlie, P. and Castelain, J. M. (1999), "Cost Estimation During Design Step: Parametric Method Versus Case Based Reasoning", *The International Journal of Advanced Manufacturing Technology*, 15, p. 895-906.

Edward, P. (2000), *Sams Teach Yourself MySQL in 21 Days*, Sams Publication, USA.

Edwards, M. (2000), "Community Guide to Development Impact Analysis", Wisconsin Land Use Research Program. March 2000. Available online: http://www.pats.wisc.edu/pdf%20documents/CommDev.pdf

Eppinger, S. T., Whitney, D. E., Smith, R. P. and Gebala, D. A. (1994), "A Model-Based Method For Organizing Tasks in Product Development", *Research in Engineering Design*.

Eriksson, H. E. and Penker, M. (2000), *Business modelling with UML: business patterns at work*, John Wiley & Sons Inc., New York.

Fatelnig, K. P. (1996), "ECOM ESA COst Modelling, A general Description. European Space Agency" http://www.estec.esa.nl/eawww/ecom/article/ecom.htm

Fiksel, J. and Hayes-Roth, F. (1993), "Computer aided requirements management'", *Concurrent Engineering: Research and Applications*, 1(2), p. 83-92.

Filipan, K. B. (2005a), "Cost Engineering - Tools for Achieving Competitive Advantage", *The 5th International Conference on Industrial Tools (ICIT 2005)*, Velenje, Slovenia, April 12-15, p. 405-410.

Filipan, K. B. (2005b), "Cost Engineering in Tool Making SMEs - Players in The Supply Chain of Most Industries", *The 3nd International Conference on Manufacturing Research (ICMR 2005) - Encouraging Applied Research in Industry*, Cranfield University, Bedfordshire, UK, 6-8 September.

Finnie, G. R., Wittig, G. E. and Desharnais, J.-M. (2000), "A comparison of software effort estimation techniques: using function points with neural networks, case-based reasoning and regression models", *Journal of Systems and Software*, 39(3), p. 281-289.

Firesmith, D. G. (2002), "Requirements Engineering", *in Journal of Object Technology*, 1(4), p. 93-103.

Flick, U. (2002). *An introduction to qualitative research.* Sage Publications Ltd, London.

Fontana, A. and Frey, J. H. (1998). Interviewing: the art of science. In: *Collecting and interpreting qualitative materials*, Edited by Denzin N. K. and Lincoln Y. S. Sage, California.

Fowler, M. (2000), *UML Distilled*, Addison Wesley, London.

Fox, M. S. and Salustri, F. A. (1994), "A One-Off Systems Engineering Model, http://www.ie.utoronto.ca/EIL/papers/abstracts/33.html", *AAAI Workshop on Artificial Intelligence and Systems Engineering, Seattle, Washington.*

Friedman, G., Hintersteiner, J. D., Tate, D. and Zimmerman, R. (2000), "Representation and Refinement of Constraints in the System Architecture", *Fifth International Conference on Integrated Design and Process Technology, Society for Design and Process Science (SDPS)*, Dallas, TX, June 4-8.

Fung R, Y, K, Popplewell K and Xie J. (1998) "An intelligent hybrid system for customer requirements analysis and product attribute targets determination". International Journal of Production Research: 36(1):13.

Fung R. Y. K, Ren, S. and Xie, J. (1996), "The prioritisation of attributes in customer requirement management". Proceedings of the 1996 IEEE International Conference on Systems, Man and Cybernetics, Beijing, P. R. China. 953.

Galliers, R. (1992), *Choosing information systems research approaches. Information Systems Research: Issues, Methods and Practical Guidelines*, Blackwell Science.

Gerson, K. and Horowitz, R. (2002). Observation and interviewing: options and choices in qualitative research. In *Qualitative research in action*, Edited by May T. Sage, London.

Galorath (2005) "SEER Tools". Citing Internet resources (WWW document). www.galorath.com, (Date of Access September 30).

Glueckstem, P., Nadav, N. and Priel, M. (2001), "Desalination of marginal water: environmental and cost impact", *Desalination*, 138, 157-163.

Goradia, T. (1993), "Dynamic Impact Analysis: Analyzing Error Propagation In Program Executions".

Gould, L. S. (2000), "Building Better Vehicles via Axiomatic Design", *Automotive Manufacturing and Production*, 112(6), p. 50-51.

Greves, D. and Joumier, H. (2003) "ESA Directorate for Industrial Matters and Technology Programmes", ESTEC, Noordwijk, The Netherlands In *ESA Bulletin,* Vol. 115

Govers, C. P. M. (1996), "What and how about quality function deployment (QFD)", *International Journal of Production Economics Proceedings of the 8th International Working Seminar on Production Economics*, 46-47, 575-585.

Guenov, M. D. and Barker, S. (2004), "Requirements-Driven Design Decomposition: A Method for Exploring Complex System Architecture", *Proceedings of DETC'04 ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Salt Lake City, Utah, USA, September 28-October 2.

Gummesson, E. (1991), *Qualitative methods in management research*, Sage publications, Ltd, London, UK.

Hamilton, D. M. and Breslawski, S. (1996), "Knowledge Acquisition for Multiple Site, Related Domain Expert Systems: Delphi Process and Application", *Expert Systems With Applications*, 11(3), p. 377-389.

Han, J. (1997), "Supporting Impact Analysis and Change propagation in Software Engineering Environments", *Proceedings of the 8th International Workshop on Software Technology and Engineering Practice (STEP '97)*, London, England, July, p. 172-182.

Ho, C.-J. and Li, J. (1997), "Progressive Engineering Changes in Multi-level Product Structure", *Omega, International Journal of Management Science*, 25(5), p. 585-594.

Hoffman, D. (1994), "A overview of concurrent engineering", *Tutorial Notes of 1994 Annual Reliability and Maintainability Symposium, California*.

Houshmand, M. and Jamshidnezhad, B. (2002), "Redesigning of an Automotive Body Assembly Line through an Axiomatic Design Approach", *"Tackling Industrial Complexity: the ideas that make a difference"*, Downing College, Cambridge, UK, 9-10 April.

Huang, G., Mak, K. and Humphreys, P. (2003), "A new model of the customer-supplier partnership in new product development", *Journal of Materials Processing Technology*, 138(1/2/3), p. 301-305.

Ince, M. (2000). "*Information systems: a methodology for capturing user requirements*". PhD Thesis, Cranfield University.

Jeziorek, P. N. (2005), "Cost Estimation of Functional and Physical Changes Made to Complex Systems" (MSc). Massachusetts Institute of Technology, Department of Mechanical Engineering. 63.

Jiao, J. and Tseng, M. M. (1999), "A requirement management database system for product definition", *Integrated Manufacturing Systems Engineering*, 10(3), p. 146-154.

Jinxin, L., Fox, M. S. and Taner, B. (1996), "A requirement ontology for engineering design", *Concurrent Engineering: Research and Applications (CERA) Journal*, 4(3), p. 279-291.

Karlsson, C., Nellore, R. and Soderquist, K. (1998), "Black box engineering: Redefining the role of product specifications", *Journal of Product Innovation Management*, 15, p. 534-549.

Kerr, C., Roy, R. and Sackett, P. (2004a), "The Integration of Specification Management in the Digital Product Development Environment for Supply Chain Interactions", *The 30th International Federation of Automotive*

Engineering Societies World Automotive Congress (FISITA 2004), Barcelona, Spain, May 23-27, F2004A019.

Kerr, C. I., Roy, R. and Sackett, P. J. (2004b), "Designing through the supply chain: A requirements perspective", *3rd International Conference on Total Vehicle Technology (TVT 2004)*, Brighton, United Kingdom, April 26-27.

Kerr, C. I. V., Roy, R. and Sackett, P. J. (2004c), "A Product Ontology For Automotive Seat Specification", *Proceedings of DETC'04 ASME 2004 Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Salt Lake City, Utah, USA, September 28-October 2.

Kidd, M. W. and Thompson, G. (2000), "Engineering design change management", *International Journal of Manufacturing Technology Management*, 11(1), p. 74-77.

Kominski, G. F., Ripps, J. C., Laugesen, M. J., Cosway, R. G. and Pourat, N. (2004), "The California Cost and Coverage Model: An Analytic Tool for Examining the Financial Impacts of Benefit Mandates" University of Califonia, Oakland, CA.

Kott, A. and Peasant, J. L. (1995), "Representation and management of requirements", *The RAPID-WS project. Concurrent Engineering: Research and Applications*, 2, p. 93-106.

Lam, W., Shankararaman, V. and Saward, G. (1999), "Requirements Change: A Dissection of Management Issues", *International Workshop on Requirements Engineering: Foundation for Software Quality (REFSQ'99)*, 5.

Lee, K. D., Suh, N. P. and Oh, J.-H. (2001), "Axiomatic Design of Machine Control System", *International Institution for Production Engineering Research*, 50(1), 109.

Lee, T. and Jeziorek, P. (2004), "An Exploratory Study of Cost Engineering in Axiomatic Design: Creation of the Cost Model Based on an FR-DP Map", *Proceedings of ICAD2004 The Third International Conference on Axiomatic Design*, Seoul, June 21-24.

Leinonen, J. and Huovila, P. (2001), "Requirements management tool as a catalyst for communication", *In: 2nd Worldwide ECC Symposium Information and*

Communication Technology (ICT) in the Practice of Building and Civil Engineering, Espoo, 6-8 June.

Li, L. and Jefferson, A. (1996), "Algorithmic Analysis of the Impact ofChanges to OO-Software", *International Conference on SoftwareMaintenance (ICSM 96)*.

Ling, D. J., Roy, R., Shehab, E., Jaiswal, J. and Stretch, J. (2006), "Modelling the Cost of Railway Asset Renewal Projects Using Pairwise Comparisons".

Lock, S. and Kotonya, G. (1999), "An Integrated Framework for Requirement Change Impact Analysis", *Proceedings of the 4th Australian Conference on Requirements Engineering*, Sydney, Australia, September, 29-42.

Makri, C., Sackett, P. J. and Roy, R. (2004), "Workflow Model of Requirements Management Documents in the Automotive Extended Enterprise", *13th Symposium PDT Europe*, Stockholm, Sweden, 13-15 October, 189-198.

Malmqvist, J. (2002), "A Classification of Matrix-Based Methods for Product Modeling", *Proceedings of Design-2002*, Dubrovnik, Croatia.

Marotz, D. (2003), "Digital Mock Up - Virtual Product Management at Karmann", *Odette International Conference*, Paris, France, September 16-17.

Marshall, C. and Rossman, G. B. (1989). *Designing qualitative research*. Sage, California.

Mason, J. (2002). Qualitative interviewing: asking, listening and interpreting. In: *Qualitative research in action*, edited by May T. Sage, London.

Martinsons, M. (1995), “Knowledge-based systems leverage human resource management expertise”, International Journal of Manpower, 16(2), 17-34, ISBN 0143-7720.

Mayer, R. J., Menzel, C. P., Painter, M. K., deWitte, P. S., Blinn, T. and Perakath, B. (1995), "Information Integration for Concurrent Engineering (IICE) IDEF3 Process Description Capture Method Report" Knowledge Based Systems, Incorporated One KBSI Place, Texas, USA. http://www.idef.com/Downloads/pdf/Idef3_fn.pdf

McCord, K. R. and Eppinger, S. D. (1993), "Managing the Integration Problem in Concurrent Engineering", *MIT Sloan School of Management Working paper, Cambridge, MA*.

McCrickard, D. S. and Abowd, G. D. (1996), "Assessing the impact of changes at the architectural level: A case study on graphical debuggers", *International Conference on Software Maintenance (ICSM 96), Monterey, CA, USA*.

McGrath, S. (2005), Development Of A Cost Model For Painted Plastic Commodities (MSc). Cranfield University, School Of Industrial And Manufacturing Science Department Of Enterprise Integration. 149.

Mo, J., P. T. and Menzel, C. (1998), "An integrated process model driven knowledge based system for remote customer support", *Computer in industry*, 37(3), p. 171-183.

Modell, M. E. (2003), *A Professional's Guide to Systems Analysis*.

Mogge, J. W. (2004), “Breaking Through The First Cost Barriers Of Sustainable Planning, Design, And Construction” (PhD). Georgia Institute of Technology, School of Civil and Environmental Engineering. 392

Montesinos, A. L. (2004), Cost Impact Analysis for Requirement Changes within the Aerospace Industry (MSc Thesis) (MSc). Cranfield University, UK, School of Industrial and Manufacturing Science. 120.

Moriconi, M. and Winkler, T. C. (1990), "Approximate reasoning about the effects of program changes", *IEEE Transactions on Software Engineering*, 16(9), p. 980-992.

Myint, S. (2003), "A framework of an intelligent quality function deployment (IQFD) for discrete assembly environment", *Computers & Industrial Engineering 25th International Conference on Computers and Industrial Engineering*, 45(2), 269-283.

Oduguwa, P., Roy, R. and Sackett, P. (2005), "A Rule Based Cost Estimating Approach for Design Requirement Changes", *The 5th Joint ISPA/SCEA International Conference and Educational Workshop*, Denver, Colorado, USA, 14-17 June.

Oduguwa, P. A., Roy, R. and Sackett, P. J. (2004), "Impact of Requirement Changes on Automotive Product Development", *The 2nd International Conference on Manufacturing Research (ICMR 2004) - Encouraging Applied Research in Industry*, Sheffield Hallam University, United Kingdom, 7-9 September, 168-173. ISDN 1-84387-088-6.

Ou-Yang, C. and Lin, T. S. (1997), "Developing an Integrated Framework for Feature-Based Early Manufacturing Cost Estimation", *The International Journal of Advanced Manufacturing Technology*, 13, p. 618-629.

Pallaver, M. (2003), "Improved Product Development Processes with Axiomatic Design Technology" http://www.axiomaticdesign.com/about/press03032003.asp

Pang, A. (1999), "Information Content on Axiomatic Design" IEEM Dept. HKUST,

Parlett, M. (1975). Evaluating innovations in teaching. In: *Curriculum Design*, edited by Greenwald J. and West R., Croom Helm, London.

Pfleeger, S. L. (1991), *The Production of Quality Software*, Macmillan, New York.

Pimmler, T. U. and Eppinger, S. D. (1994), "Integration Analysis of Product Decomposition", *ASME Design Theory and Methodology Conference,*, Minneapolis, MN, USA, September, 1-9.

Pivetz, T., Strauss, W., Sell, R. and Nagaraja, J. (2004), "Potential Impact of the NCS on Priority Health Outcomes" National Children's Study Program Office National Institute for Child Health and Human Development, Columbus, OH.

Price (2005) PRICE H, The Hardware Estimating Model.Citing Internet resources (WWW document). www.pricesystems.com, (Date of Access September 30).

Pullman, M. E., Moore, W. L. and Wardell, D. G. (2002), "A comparison of quality function deployment and conjoint analysis in new product design", *Journal of Product Innovation Management*, 19(5), 354-364.

Remenyi, D. and Williams, B. (1996), "The nature of research: qualitative or quantitative, narrative or paradigmatic?" *Information Systems Journal*, 6(2), 131-146.

Robson, C. (2002), *Real world research: a resource for social scientists and practitioner-researchers*, Blackwell, Oxford, UK.

Rouibah, K. and Caskey, K. R. (2003), "Change management in concurrent engineering from a parameter perspective", *Computers in Industry*, 50(1), p. 15-34.

Roy, R. (2003), "Cost Engineering: Why, What and How?" *Decision Engineering Report Series*, Cranfield University,

Roy, R. (2005), "Cost Engineering - A Necessity for Survival in Europe", *The 5th International Conference on Industrial Tools (ICIT 2005)*, Velenje, Slovenia, April 12-15, p. 369-376.

Roy, R., Allen, D. and Zamora, O. (2004a), "Cost of Photochemical Machining", *Journal of Materials Processing Technology*, 149(1-3), p.460-465.

Roy, R., Colmer, S. and Griggs, T. (2004b), "Estimating the Cost of a New Technology Intensive Automotive Product: A Case Study Approach", *International Journal of Production Economics*, 18 pages.

Roy, R., Forsberg, S., Kelvesjo, S. and Rush, C. (2001), "Quantitative and qualitative cost estimating for engineering design", *Journal of Engineering Design*, 12(2), p. 147-162.

Roy, R., Kerr, C. I. V. and Sackett, P., J. (2004c), "Requirements Management for the Automotive Extended Enterprise: The Next Evolution in Digital Product Development", *14th International CIRP Design Seminar.*, Cairo, Egypt, May 16-18.

Roy, R., Kerr, C. I. V. and Sackett, P. J. (2004d), "Requirements Management for the Automotive Extended Enterprise: The Next Evolution in Digital Product Development", *The 14th International CIRP (International Institution for Production Engineering Research) Design Seminar 2004 (CIRP 2004 Dn)*, Design in the Global Village, Cairo, Egypt, May 16-18, p. 1-12.

Roy, R., Rios, J. and Lopez, A. (2005), "Cost Impact Analysis for Requirement Changes within the Aerospace Industry", *The 3nd International Conference on Manufacturing Research (ICMR 2005) - Encouraging Applied Research in Industry*, Cranfield University, Bedfordshire, UK, 6-8 September.

Roy, R., Sackett, P. J. and Sehdev, K. (2002), "Integrated Requirements Management for Digital Product Development (e-RM)" Cranfield University, Bedford, UK.

Roy, R., Souchoroukov, P. and Koponen, H. S. (2003), "Information Requirements for Cost Estimating in the Automotive Industry", *The 8th Annual ASME Design for Manufacturing Conference*, Chicago, Illinois, USA, September 2-6, p. 195-204.

Rush, C. (2002), Formalisation and Reuse of Cost Engineering Knowledge (Ph.D). Cranfield University, School of Industrial and Manufacturing Science. 303.

Rush, C. and Roy, R. (2001a), "Capturing Quantitative & Qualitative Knowledge for Cost Modelling within a CE environment", *ISPE International Conference on Concurrent Engineering: Research and Applications, Anaheim, Los Angeles*, p. 209-218.

Rush, C. and Roy, R. (2001b), "Expert Judgement in Cost Estimating: Modelling the Reasoning Process", *Concurrent Engineering Research and Applications (CERA) Journal, Special Issue: Cost Engineering in CE*, 9(4).

Sarasua, A., Roy, R., Taratoukhine, V. and Giannopoulos, N. (2004), "Printed Circuit Board Design and Manufacturing Cost Estimation: The Challenges", *The 2nd International Conference on Manufacturing Research (ICMR 2004) - Encouraging Applied Research in Industry*, Sheffield, UK, September 7-9, p. 222-227.

Sawyer, P., Sommerville, I. and Viller, S. (1999), "Capturing the Benefits of Requirements Engineering", *IEEE Software*.

Schweitzer, L. (2003), "Keynote speech", *Odette International Conference 2003*, Paris, France, 16-17 September.

Scotland, A. (2005), "A Scottish prescription: Managing the use of medicines in hospitals" Scotland.

Shefelbine, S. J. (1998), “Requirements Capture for Medical Device Design” (MPhil thesis). Cambridge University, Engineering Department.

Shen, X. X., Tan, K. C. and Xie, M. (2001), "The implementation of quality function deployment based on linguistic data", *Journal of Intelligent Manufacturing*, 12, p. 65-75.

Simon, H. (1972), *Theories of Bounded Rationality*, R. Radner, North Holland.

Soderborg, N. R., Crawley, E. F. and Dori, D. (2002), "System Definition for Axiomatic Design Aided by Object-Process Methodology", *The Second International Conference on Axiomatic Design ICAD 2002, Cambridge, MA, USA*, 10-11 June, p. 134-140.

Souchoroukov, P. (2004), Improvement of Cost Estimating Internal Practice (Ph.D). Cranfield University, UK, School of Industrial and Manufacturing Science. 273.

Souchoroukov, P., Roy, R. and Mishra, K. (2002), "Data and Information in Cost Engineering", *Conference of The Society of Cost Estimating and Analysis*, Scottsdale, USA, June 11-14, p.44-56.

Staples, M. L. and Bieman, J. M. (1999), *3-D Visualization of Software Structure*, Academic Press.

Stevens, R. and Martin, J. (1999) What is requirements management?Telelogic AB, http://www.telelogic.com/ (Date of Access 4 August 2006).

Steward, D. V. (1981), "The Design Structure System: A Method for Managing the Design of Complex Systems", *IEEE Transactions on Engineering Management*, EM-28(3).

Steward, D. V. (1991), "Planning and Managing the Design of Systems", *Proceedings of the Portland International Conference on Management of Engineering and Technology, PICMET 91, Portland, Oregon*.

Stewart, R. D. (1991), *Cost Estimating*, John Wiley & Sons, Inc.

Sudjianto, A. and Otto, K. (2001), "Modularization to Support Multiple Brand Platforms", *Proceedings of ASME Design Engineering Technical Conferences, Paper No DETC2001/DTM-21695*, Pittsburgh, Pennsylvania, USA, 9-12 September.

Suh, N. P. (1995), "Designing-in of Quality Through Axiomatic Design", *IEEE Transactions on Reliability*, 44(2), p. 256-264.

Suh, N. P. (2001), *Axiomatic Design: Advances and Applications*, Oxford University Press, New York.

Sutinen, K., Almefelt, L. and Malmqvist, J. (2002), "Supporting Concept Development Using Quantitative Requirements Traceability", *Proceedings of INCOSE-2002*, Las Vegas, NA, USA.

Svensson, Daniel and Malmqvist (2001), "Integration of Requirement Management and Product Data Management Systems", *Proceedings of the 2001 ASME Design Engineering Technical Conferences*, Pittsburgh, Pennsylvania, USA, September 9-12.

Tang, J., Y.K. Fung, R., Xu, B. and Wang, D. (2002), "A new approach to quality function deployment planning with financial consideration", *Computers & Operations Research*, 29(11), 1447-1463.

Tate, D. (1999), A Roadmap for Decomposition: Activities, Theories, and Tools for System Design (PhD). Massachusetts Institute of Technology, Department of Mechanical Engineering. 210.

Taylor, I. M. (1997), "Cost engineering - A feature based approach", *The 85th Meeting of the AGARD Structures and Material Panel*, Aalborg, Denmark, October 13-14, p. 1-9.

Ten Brinke, E., Lutters, D., Streppel, A. H. and Kals, H. J. J. (1999), "Cost Model Definition by Means of Cost Structures", *In: Proceedings of the 8th International Conference on Sheet Metal: SheMet'2000; (2000); Shirvani, B.; Geiger, M.; Kals, H.J.J.; Singh, U.P. (ed.), Birmingham.*, 79-88.

Terwiesch, C. and Loch, C. H. (1999), "Managing the Process of Engineering Change Orders: The Case of the Climate Control System in Automobile Development", *Journal of Product Innovation Management*, 16(2), p. 160-172.

Thomson, G. A. (2001), "Requirements engineering - Laying the foundations for successful design", *13th International Conference on Engineering Design*, Glasgow, UK, August 21-23.

Trappey, C. V., Trappey, A. J. C. and Hwang, S.-J. (1996), "A computerized quality function deployment approach for retail services", *Computers & Industrial Engineering*, 30(4), 611-622.

Tseng, M. M. and Jiao, J. (1998), "Computer-aided requirement management for product definition: a methodology and implementation", *Concurrent Engineering Research and Application*, 6(2), p. 145-60.

Vanegas, L. V. and Labib, A. W. (2001), "A fuzzy quality function deployment (FQFD) model for deriving optimum targets", *International Journal of Production Research*, 39(1), p. 99-120.

Wang, J. (1999), "Fuzzy outranking approach to prioritize design requirements in quality function deployment", *International Journal of Production Research*, 37(4), p. 899-916.

Wang, Q. and Stockton, D. (2001), "Cost Model Development using Artificial Neural Networks", *Aircraft Engineering and Aerospace Technology*, 73(6), p. 536-541.

Westbrook, R. (1995). Action research: a new paradigm for research in production and operations management. *International Journal of Operations and production Management*, 15 (12), 6-20.

Wierda, L. S. (1991), "Linking Design, Process planning and cost information by feature-based modelling", *Journal of Engineering Design*, 2(1), p. 3-19.

Winchell, W. (1989), *Realistic Cost Estimating for Manufacturing*, Dearborn MI, USA.

Wright, I. C. (1997), "A review of research into engineering change management: implications for product design", *Design Studies*, 18(1), p. 33-42.

Wu, B. (1994), *Manufacturing systems design and analysis: context and techniques*, Chapman and Hall, London.

Yassine, A. A. (2002), "An Introduction to Modeling and Analyzing Complex Product Development Processes using the Design Structure Matrix (DSM) Method".

Yassine, A. A. and Braha, D. (2003), "Complex Concurrent Engineering and the Design Structure Matrix Approach. Concurrent Engineering", *Research and Applications*, 11(3).

Yassine, A. A., Whitney, D. E. and Zambito, T. (2001), "Assessment of Rework Probabilities for Simulating Product Development Processes Using the Design Structure Matrix (DSM)", *Proceedings of DETC '01/DTM-21693*, Pittsburgh, Pennsylvania, USA, 9-12 September, p. 1-9.

Yen, J., Liu, X. and Teh, S. H. (1994), "A fuzzy logic-based methodology for the acquisition and analysis of imprecise requirements", *Concurrent Engineering: Research and Applications*, 2, p. 265-277.

Zadeh, L. (1965), "Information and Control", *Fuzzy Sets*, 8(3), p. 338-353.

Zhang, J. (1996), "Information Modelling for Manufacturing Systems: A Case Study", *Robotics and Computer-Integrated Manufacturing*, 12(3), p. 217-225.

Zhang, Y. F., Fuh, J. Y. H. and Chan, W. T. (1996), "Feature-based Cost Estimation for Packaging Products Using Neural Networks", *Computers in Industry*, 32(1), p. 95-113.

Zhao, J. (1999), "A Consistent Manufacturing Data Model to Support Virtual Enterprises", *International Journal of Agile Management Systems*, 1(3), p. 150-158.

Zhou, M. (1998), "Fuzzy logic and optimization models for implementing QFD", *Computers and Industrial Engineering*, 35, p. 237-240.

APPENDIX A E-RM QUESTIONNAIRE

Application of Methodology - Validation

CIAM Purpose

e-RM Questionnaire

REQUIREMENTS MANAGEMENT FOR DIGITAL PRODUCT DEVELOPMENT

Introduction

The Cranfield electronic Requirements Management team's project on 'Integrating the Requirements in Digital Product Development for the Automotive Industry – The e-RM Project aims to improve an organisation's capability to develop, capture and manage requirements and constraints in the Extended Enterprise. The benefit to industry will be the visibility of requirements and constraints during design and manufacturing together with the cost impact of any design change. The team is led by Dr Rajkumar Roy from Enterprise Integration, Cranfield University, supported by Professor Peter Sackett and Kamal Sehdev. The industrial partners for the e-RM project include Nissan Technical Centre Europe, Johnson Control Automotive, EDS and the Society of Motor Manufacturers and Traders (SMMT). The project is being co-ordinated by Clive Kerr with researchers Chrysanthi Makri and Patrick Oduguwa.

The purpose of this questionnaire is to gather knowledge on the following:

- ✓ Creation of a Process Map and Visualisation of best practice inside the company
- ✓ Definition of the Terminology used
- ✓ Identification of the key success factors

REFERENCE NO.

NOTE: Please feel free to add any other relevant comments to your answers

a. What are your expectations from this project?

b. What do your definition of Requirements Management?

1 Management of Requirements

1.1 How often do you have to deal with requirements?

- Never ☐
- Rarely ☐
- Very Often ☐

1.2 From these what percentage (approx.) refers to changes?

1.3 What process do you follow when you receive a new requirement?

1.4 What are your inputs- outputs of these processes?

1.5 What types of requirements do you handle in the organisation?

1.6 What is the frequency of the mentioned requirements? Examples?

1.7 Where is a Requirement implemented inside your organisation?

1.8 Are all requirements automatically allocated?

1.9 What terms do you use in order to communicate these requirements (is there a code, common language, jargon, etc)

1.10 Do you categorise requirements and how do you categorise them? Is there a classification of the requirements to functional and non-functional?

1.11 How many people are involved in the requirements management process (directly/indirectly) in the organisation?

1.12 Do you have problems receiving/reading/interpreting requirements sent by the OEM

1.13 If you find any how do you manage them?

1.14 Is there a prioritisation of the requirements? If yes how do you prioritise them?

1.15 Is there full traceability of the requirements handling? If yes in what form?

1.16 Is there an adequate understanding of the requirements from the very early phase of a project?

1.17 Who are the stakeholders of these requirements?

1.18 Do you use a specific model for the handling of the requirements?

1.19 What is the level of concurrency in your processes?

1.20 Do you ever question a Requirement?

1.21 Do you ever verify if you have achieved a certain Requirement?

2 Bottlenecks and Problems

2.1 What are the problems in the handling of the Requirements Management

2.2 Of these problems which are those that appear because of the quality of the existing requirements system engineering

2.3 How frequent do they appear in an everyday basis

2.4 How often do you find yourselves disagreeing with those changes in requirements? Do you communicate these to the OEM? If yes how?

2.5 Did you ever come across conflicts between requirements? If yes why do you think they appeared?

3 Management of Changes

3.1 How do you manage changes in design?

3.2 What process do you follow when you receive a requirement change?

3.3 What are your inputs- outputs of these processes?

3.4 How many people are involved in the handling of those changes?

3.5 How does the existing system help in the communication of those changes from the OEM to your organisation?

3.6 How long does it take to communicate these problems (from concept to the implementation of the change)

3.7 What is the impact of changing a particular requirement?

3.8 How do you assess the impact of a change?

3.9 What is the impact in lead time?

3.10 Do you have to estimate cost? If yes how long does it take?

3.11 What is the impact in cost?

4 Requirements Translation/Decomposition

4.1 What form does the requirement from OEM take?

4.2 How is OEM envelope described?

4.3 How do you translate the OEM seat envelope into an appropriate design?

4.4 How do you decompose your seat design into its components parts?

5 IT Infrastructure

Please indicate the Tools used (Software system), Version of the system and Platform you currently use the system.

5.1 What IT systems do you currently have in supplier?

5.2 What tools or systems do you use to collect and manage requirement from OEM?

5.3 Do you do any translations to the requirements? If yes, do you use any system?

5.4 Do you have any problems translating/interpret these requirements?

5.5 Do you use any system to determine lead-time?

5.6 How do you determine which departments will be involved in a particular specifications?

5.7 How do you communicate these specifications within various supplier departments?

5.8 How do you classify specifications?

5.9 Do you use any systems to verify specification before manufacturing product?

5.10 What are the general communication medium between supplier and OEM (Specification)?

5.11 How does OEM communicate requirement changes to you?

5.12 Do you use any system to measure cost impact of changes on requirements?

5.13 Do you use any system to measure resource impact of changes on requirements?

5.14 How does OEM communicate design to you?

5.15 How does OEM communicate design changes to you?

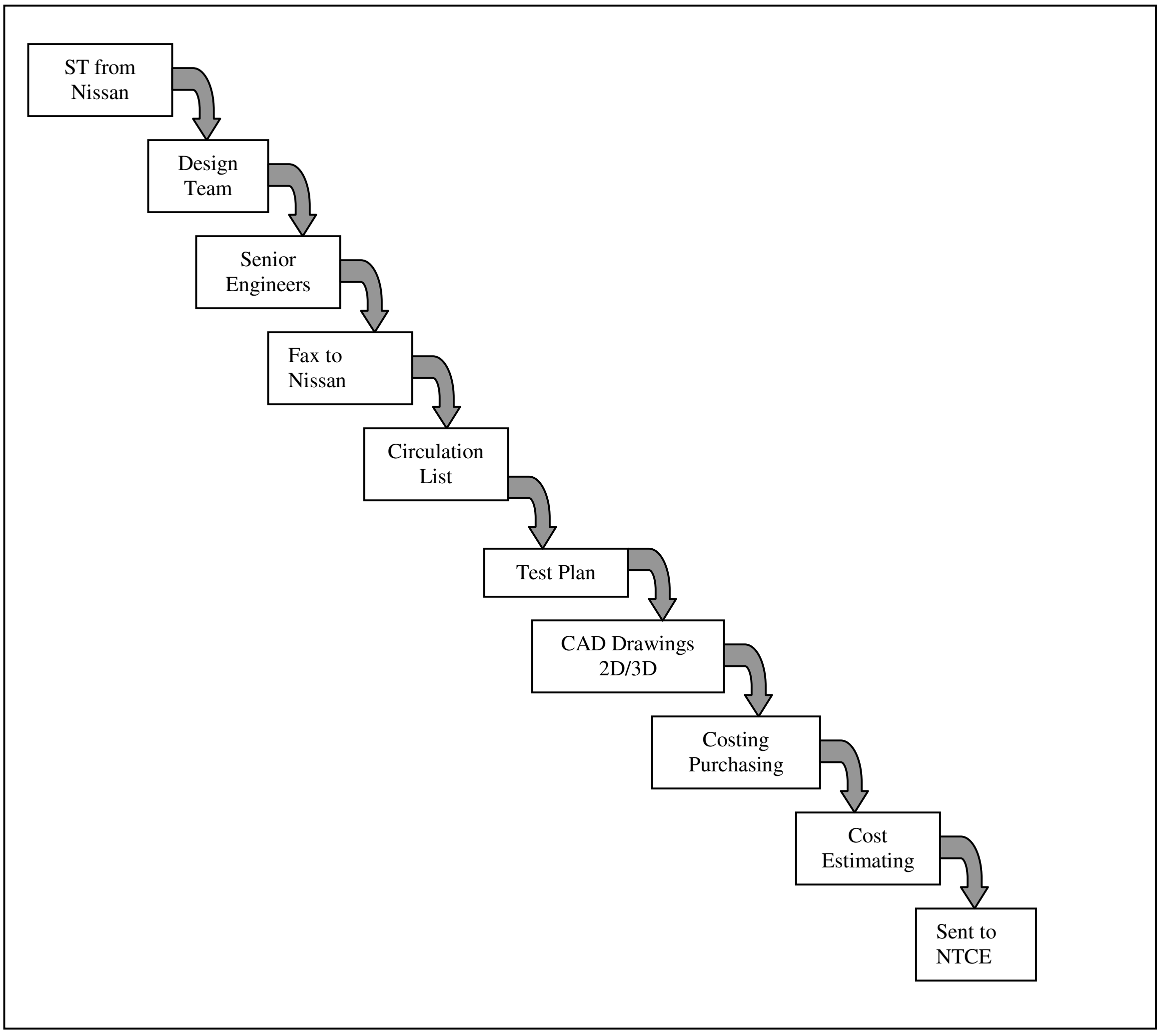
5.16 Do you use any system to measure cost impact of changes on design?

5.17 Do you use any system to determine the counter measures from changing specification/requirements?

5.18 If you make or suggest changes to OEM, do you have to get it approved by OEM?

APPENDIX B SAMPLE INTERVIEW TRANSCRIPT

Interviewee's area of competence is in design. He is responsible for all design activities relating to NMUK products (Micra, Almera and Premera), both new models and current models.



Design Process from Design Managers point of view

The Specification Tender (ST) is sent to JCA and forwarded to the design team. The design administrator logs the ST into JCA's database, the ST is stamped out, adding a date to the stamp and issued a reference number. Design manager chooses a senior engineer (usually a senior design engineer) who will be responsible for the particular project, the senior engineer reviews the ST, and if its OK JCA faxes NTCE to say they have received and accepted it. At the same time, the ST is circulated internally with a circulation list attached to it. The circulation document has the names of all the people that needs to sign it, it is circulated round the various departments engineering,

development, test, account (estimating) and production. The ST is review weekly by the SDT, and action are taken we have to produce test plan, confirm drawings, we have to confirm submission date i.e. when we will complete the drawing (including changes if there is any) and send it back to Nissan for approval. We also have to get some costing information either from purchasing or from estimating department. A package of about 4 or 5 document is put together, which Nissan requires, the only document that is required design is the Application For Drawing Acceptance (AFDA) and the actual drawings themselves, this basically is a drawing we send the drawings back with, to Nissan. It has a reference, once gets to Nissan the reference gets logged in their system. We eventually get the drawing back as a signed off drawing.
Test department will put together a test plan and STRS and Estimation department will put together a cost estimate. Both will go back to NTCE cost, lead-time, testing implications and drawings produced and modified, for them to sign on. NTCE looks at the documents internally. NTCE design people looks at the interpretation from JCA to make sure there are no mistakes on the documents.
There are four options (concerning NTCE's reply):

1. Cancelled—reject i.e. NTCE does not what to make the change
2. Approved—totally approved
3. Approved—with some corrections due to Nissan's mistakes
4. Approved—with some corrections due to JCA's mistakes

JCA is scored down if the corrections are due to their mistakes. NTCE has a full system for monitoring suppliers' response (i.e. not just supplier response, but technical, quality of deliverables from suppliers). One of the measurements is to see how many corrections JCA has on drawing (option 4 above). NTCE usually release a report called SEIS every quarter.
If the request is a major change (spare part components that affects Nissan process), which will mean the spare parts for the vehicle will no longer be suitable, i.e. it will not fit anymore, in cases like this we will have to go through the approval system.
If it is an internal change we do not need for the approval system. Nissan sends back the approval documents to JCA and at the same time NTCE sends design notes (DN) to NMUK's Design Changes Control department (DCC). NMUK are responsible for making sure the changes are implemented. NTCE's responsibility finishes with the release of the DN to NMUK. At this point JCAS's design work finishes, once a DN is release and JCAS have made the changes, JCAS adds the DN to the drawings, makes the corrections and issue it. NMUK's DCC will control the implementation contacting JCA's Material Handling department to confirm an implementation date. Once that date is confirmed with NMUK, NMUK will release an official document to JCA. Material Handling department will have to sign to say it will be implemented on that date. There is close co-ordination between NMUK's DCC and JCA's Control department to make sure the change goes in, right down to the particular vehicle, on a particular shift and on a particular date.

How do you manage design change?
Internal changes: JCA identifies design changes drawing changes, 3D data; change will have reference called design note number. Design notes are produced with 2D and 3D drawing, which is checked by design manager and other senior managers. Design team will complete a despatch note, which tells JCA admin department where the drawing goes to i.e. to suppliers, completes a transmission note, which is sent to the recipient of the CAD data. The recipient sends back acknowledgement to confirm

receipt of CAD data (2Ddrawings and 3D data, design notes, transmission notes, dispatch notes) all bundled together. The admin distributes the bundle if it is internal or external. The dispatch note will indicate if the bundle is internal or external. If it is internal issue the bundle goes to the Purchase Department, who has 2 buyers on-site, one for the metal parts i.e. press parts and another for plastic parts. There are other items like cables, heaters and auxiliary components, which are handled by external buyers. JCA has a list of supplier, which is identified on the dispatch notes. If it is an external change we give them contacts, where they send the drawing and information. For external buyers the Purchasing Manager will send the drawings and DN to the suppliers for quote.
Sometimes production will go ahead without an ST. This is usually based on the result of design change discussions between NTCE and JCA. The impact of this is that the purchasing department cannot cost items since there is no ST to base it on.
ST started in 1981, JCA has archived all STs and DNs, risk factor. JCA tries to be concurrent, but at the detriment of JCA.
If Nissan has a quality concern during a build that is feedback through NTCE from NMUK, so NMUK identifies the quality concern, NTCE and JCAS agrees what the current measure is with NMUK. Then NTCE will release an ST approving the change, if it is a major change. For each trial build you get 2 or 3 ST, with various build on them, and normally Nissan has about 3 or 4 trial builds. For late changes JCAS commence with the build without first receiving ST from Nissan, this is so that they JCAS, can meet up with SOP. There is a level of trust. Impact of changes are discussed in in-house meeting at JCAS, meeting can be arranged in short notice, impact on cost, time and resources are discussed in such mentioned meetings.
There is no in-house prioritisation. Nissan handles prioritisation. There is historical ST going back ten years, for traceability. ST system came in around 1981. ST and DT all have JCAS reference on them for tracking purpose. JCAS is quite concurrent, they respond to multiple tasks and request from Nissan, which are dealt with. From design point of view JCAS work concurrently with the design engineers at NTCE, fundamentally the system should run concurrently, we send the drawings to Nissan they should be able to approve them fairly quickly, and release them to both NMUK and JCAS. The problem is that we currently work in serial mode, we do our bit send it to NTCE, they do their bit (review). JCA numbering system is different from Nissan's numbering system; JCA seems to be willing to adopt Nissan nomenclature.
Constraints are mainly to do with internal communication mode and circulation of critical documents e.g. Specification Tender (ST). Sometimes the ST is ambiguous. There are also problems translating CATIA to IDEAS.
Timing is sometimes an issue, since changes can come in at any time.
Communication with JCAS suppliers (second tier suppliers) is done via fax or verbally.

IT systems used are IDEAS (9M2), ENGDAT, and MS Office.

Areas of improvements: better communication between members of the SDT, regular/scheduled in-house meeting, quick return of approval from NTCE and better coordination between NMUK and NTCE.

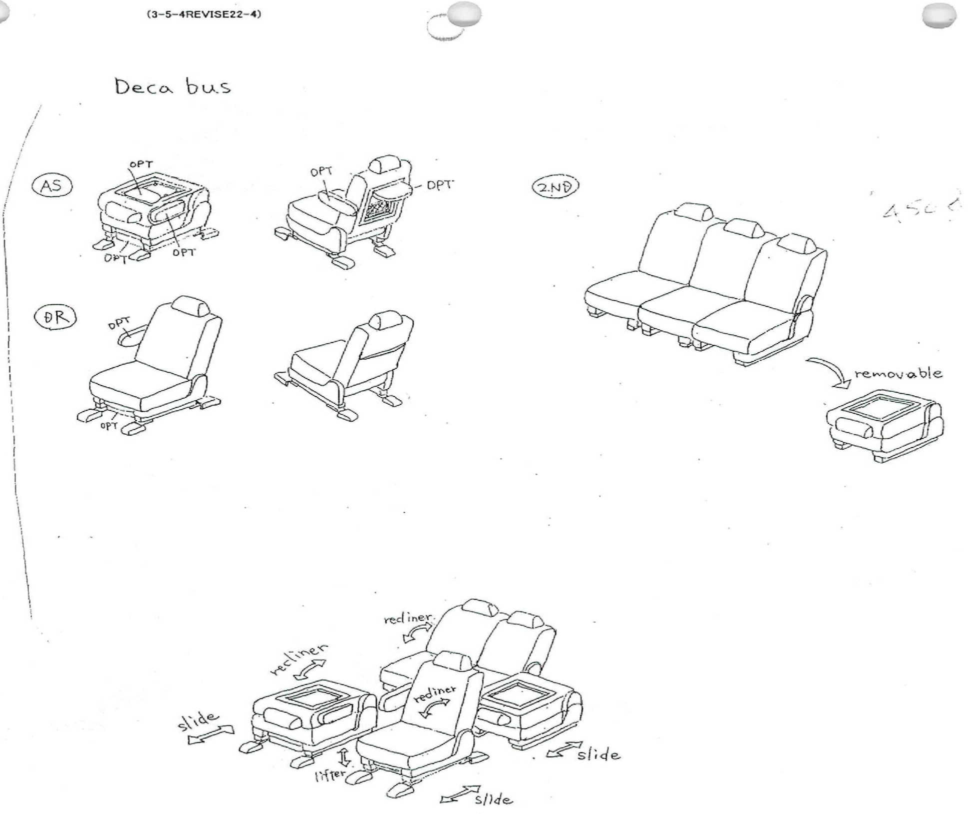
APPENDIX C SAMPLE SEATING SYSTEM DOCUMENTS

Extracts from Request for Quotation

Feature List

3−5−4 (Tentative) Feature List

					Deca bus
					1-C
1st	Seat type				Separate
	Safety	Out Side Lap belt (with pretension) Seat mount		DR/AS	○
		Inside Lap belt (with pretension)Seat mount		DR/AS	○
		Side Air Bag		DR/AS	※85%
		Active Head Rest		DR/AS	○
		Occupant sensor		AS	−
		AABT Sensor		AS	○
	Adjuster	Slide	Travel ; More than 240mm ／ Pitch ; Less than 12mm	DR/AS	○
		Lifter	Travel ; More than 50mm	DR	○
		Recliner	Pitch ; Less than 2°	DR/AS	○
		Lumbar Support		DR	○
	Addisional function items	Power seat (DR: slide, lifter, recliner AS: slide, recliner)		DR/AS	−
		Power seat memory		DR	−
		Heated seat		DR/AS	※10%
		Lifter lever location		DR	OTR
		Recliner lever location		DR/AS	OTR
		DR armrest		−	※60%
		AS armrest		−	※60%
		DR Seat Back Pocket		−	○
		AS Seat Back Pocket		−	○
		Seat side folding table		DR	−
		Back folding table with tray		AS	○
		Under tray		DR or AS	※60%
		Picnic table		AS	※60%
		Convenience hook		AS	−
		Slide Covers		DR/AS	○
		Iso fix		AS	※10%
		CD changer with brkt		DR or AS	−
		NAV unit with brkt		DR or AS	−
		MD change with brkt		DR or AS	−
					2-F
2nd	Seat type				−
	Numbers of persons to be seated				3
	Devision				−
	Safety	Side hrst		RH/LH	○
		Ctr Hrst			○
		Side passenger Inside lap belt seat mount		RH/LH	○
		Ctr passenger lap belt seat mount			○
		Side passenger shourder belt seat mount		RH/LH	−
		Ctr shourder belt seat mount			−
		Integrated child seat			−
	Adjuster	Slide	Travel ; 280mm ／ Pitch ; Less than 12mm	RH/LH	−
			Travel ; More than 150mm ／ Pitch ; Less than 12mm	RH/LH	○
			Travel ; 380mm (Long rail)	RH/LH	−
			Travel ; 310mm (Long rail)	RH/LH	−
		Recliner	Pitch ; Less than 4°	RH/LH	○
	Additional function items	W/Folding		RH/LH	−
		Fold Down with cushion		RH/LH	−
		Back folding table with tray		RH/LH/(CTR	○
		Swivel		RH/LH	−
		Removable		RH/LH/CTR	○
		CTR Armrest			−
		Ctr seat back folding armrest			−
		Cup Holder built-in for ctr armrest			−
		Walk-in mechanisum with inter-lock		RH/LH	−
		Walk-in Lever		RH/LH	−
		Both side armrest		RH/LH	−
		ISO-FIX location(seat)		RH/LH	○
		ISO-FIX location(body)		RH/LH	
		Tether Anch with seat		RH/LH	○
		Seat back Luggage hook		RH/LH	−
		Slide Covers,Finisher			○
3rd	Seat type				
	Numbers of persons to be seated				
	Devision				
	Safety	Side hrst		RH/LH	
		Side passenger Inside lap belt seat mount		RH/LH	
		Ctr passenger lap belt seat mount			
	Adjuster	Slide	Travel ; More than 150mm	RH/LH	
		Recliner	Pitch ; Less than 4°	RH/LH	
	Addisional function items	Fold Down with cushion			
		Side Tumble		RH/LH	
		Seat back Luggage hook		RH/LH	
		Arange Levers enable to use from forward and backward			
		Slide Covers, Finisher			



Principal Function

3-6-1 (3/3)

Principal Functions of a Seat and Examples of Failure Grades

Explanation of the table
This table lists failure grades and the corresponding functions and failure modes. Also, it shows what environmental or loading condition chiefly affects each failure mode.
Note:
This table gives examples for reference only, and it does not cover all functions nor all failure grades. In examining the reliability of each seat, therefore, careful consideration must be given to all possible functions, failure modes, environmental conditions, loading conditions, etc. and their various combinations.

a: Failures that fall into vehicle-level failure grade A
b: Failures that fall into vehicle-level failure grade B
c: Failures that fall into vehicle-level failure grade C
d: Failures that fall into vehicle-level failure grade D
*: Failures that affect the society or environment (but not directly cause inconvenience to the customer)

Primary	Secondary	Tertiary	Seat system level (Seat functions and structure)	Visibility		Holding		Movement, operation and adjustment									Discomfort and perceived quality														Harm and damage						Society and environment			
			Failure modes	Considerably obstructing the occupant view	Obstructing the occupant view to some extent	Completely disabling the holding or restraining function	Impairing the holding or restraining function	Moving against the occupant will (malfunction)	Not moving at all	Not moving smoothly	Difficult to use	Not allowing the occupant to sit in a correct posture	Very difficult to adjust	A little difficult to adjust	Requiring great muscular strength or grasping power to adjust	Lack of operation space	Insufficient sturdiness or rigidity	Giving a pain or a feeling of uneasiness	Producing unpleasant vibrations (backlash)	Fatiguing	Being felt hot or cold	Emitting an unusual or unpleasant odor	Objectionable color or pattern	Exposure of parts offensive to the eye (mechanical devices)	Presence of wrinkles or frays	Getting dirty easily or difficult to clean	Unpleasant touch, e.g. sticky or rough surface	Making noise	Being too tight and uncomfortable to sit in	Producing unpleasant static electricity	Causing a slight injury, e.g. scratches	Giving a serious burn to the occupant	Causing the symptoms of a disease	Giving scratches to articles the occupant wears	Color or prints easily transferred to the occupant clothes	Causing damage to baggage	Causing a vehicle fire	Emitting substances detrimental to the environment	Much time required for disassembly and reassembly	Components impossible to reuse
Driving	To ensure a proper driving posture	To hold the occupant body	To hold the lower body			a	b	b										d		d									d		d									
			To hold the upper body			a	b	b										d		d									d		d									
			To hold the arms			d	d	d										d		d									d		d									
			To hold the head			d	d	d										d		d									d		d									
		Operability during driving	To secure space for the operation of pedals										b	d															d											
			To secure space for steering										b	d															d											
			To adjust the longitudinal position					b	c	d		c			d	d																								
			To adjust the height					c	d	d		d			d	d																								
			To adjust the seat-cushion angle					c	d	d		d			d	d																								
			To adjust the form of the seat back					c	d	d		d			d	d																								
			To adjust the seat-back angle					b	c	d		c			d	d																								
			To adjust the form of the seat back					c	d	d		d			d	d																								
		Front, side and rear views	To ensure visibility through windows		d																																			
			To ensure rear visibility		c	d																																		
			To ensure visibility through mirrors	c	d																																			
	Carrying of baggage	Loading of baggage	To be detachable and movable										d	d	d	d																								
			To have a detachable and movable seat cushion										d	d	d	d																								
			To have a detachable and movable seat back										d	d	d	d																								
			To hold baggage and to secure space for it			c	d																													d				
			To secure baggage			c	d						d	d	d	d																				d				
Convenience	Access space	Ease of getting in and out of the vehicle	To provide space for getting in and out										c																d											
			To enlarge the space for getting in and out (walk-in)										c		d	d																								
			To hold the occupant body			c											d	d													d									
			To hold the occupant hips			c											d	d													d									
			To support the occupant upper body			d											d	d													d									
Comfort	To ensure seating comfort	To hold the occupant in a good posture	To hold the lower body			c	d	d										d		d									d											
			To hold the upper body			c	d	d										d		d									d											
			To hold the arms			d	d	d										d		d									d											
			To hold the head			d	d	d										d		d									d											
			To hold a child seat			c	d																																	
			To adjust the longitudinal position				d	c	c	d	d	d			d	d																								
			To adjust the height				d	d	d	d	d	d			d	d																								
			To adjust the seat-cushion angle				d	d	d	d	d	d			d	d																								
			To adjust the seat-cushion form				d	d	d	d	d	d			d	d																								
			To adjust the seat-back angle				d	c	c	d	d	d			d	d																								
			To adjust the seat-back form				d	d	d	d	d	d			d	d																								
			To adjust the seat orientation				d	c	c	d	d	d			d	d																								
			To ensure spaciousness for the vehicle									d																	d											
		Environment	To adjust the temperature																			d										b								
		Noise and vibration	Not to produce vibration (backlash)																d																					
			To absorb or reduce vehicle vibration																d									d												
			Not to produce noise																									d												
		Odor	Not to emit any unpleasant odor																		d																			
	Quality appearance	Appearance	Decoration, covering, concealment, interception of light																				d	d	d	d														
		Touch and feeling of rigidity	To ensure "quality" touch																								d													
			To ensure "quality" rigidity														d																							
To Safety	Safety under normal conditions	To protect the occupant and baggage	To protect the occupant (from injuries, burns, etc.)																											d	d	b	b							
			To protect baggage																															d	d	d				
	Safety in the event of a crash	Passive safety	To hold the occupant restrained			a	b																																	
			To hold the child seat restrained			a	b																																	
			Not to interfere with the functioning of any restraint device			a	b																																	
			To protect the occupant from baggage			b	c																																	
Vehicle fire			To be flame retardant or noncombustible																		d	d										b					a			
Society and environment	Environment		To allow parts to be recycled or reused																																				*	*
			To protect the environment (Not to pollute it)																																			*		
	Serviceability		To protect the worker (from injuries)																												*									
			To ensure high working efficiency																																				*	*
		Environmental and loading conditions, and factors	Temperature and humidity		O			O	O	O		O			O		O				O	O	O	O	O		O			O		O	O		O		O			
			Light																		O		O	O	O		O								O		O			
			Chemical substances, chemicals, sweat					O	O	O		O			O		O				O		O	O	O	O	O						O		O		O			
			Electromagnetic wave, magnetic field					O	O			O																									O			
			Vehicle posture			O	O	O	O	O		O																												
			Vertical acceleration (vibration)																O	O				O				O	O							O	O			
			External force (repeated and continuous)			O	O					O											O	O	O			O	O								O			
			External force (abnormal)			O	O	O	O	O		O						O					O	O	O						O			O		O	O			
			Breakage, deformation, degradation			O	O	O	O	O		O	O	O	O		O	O	O	O	O	O						O	O		O					O	O			
			Intrusion and catching of foreign objects			O	O	O	O	O		O			O				O									O									O			
			Children's mischief			O	O	O	O	O		O			O			O											O		O	O					O			
			Spilling and adhesion of drinks, excretion, etc.					O		O		O									O		O	O	O	O	O										O			

Seat Basic Dimension

3-6-16 SEAT BASIC DIMENSION TABLE

1st Seat

			DOM				EUR			NAM	
			RHD				RHD/LHD			LH	
			W32G [GN]	J32B C-MPV	W32C [NR]	W32E [ZR]	B32A	W32C [NR]	W32E [ZR]	L32H [HS]	deca bus
Seat TypeA			Separate	Separate	Separate	Separate	Separate	Separate	Separate	Separate	Separate
Core Dimension	Neutral Tolso Angle	-	21	21	21	21	21	21	21	21	21
	Cush Widthl	-	530	515	520	530	530	530	530	530	530
	Cush Length□	H.P～Cush Fr Edgegle	365	365	367	365	365	365	365	365	365
	Back Widthr	-	530	515	500	530	530	530	530	530	530
	Back Height□	H.P～Back Top Edgele□	580	580	570	580	580	580	580	580	580
	H/R Heighto	H.P～Along Torso Lowest Position	765	765	765	765	765	765	765	765	765
		H.P～Along Torso Highest Positior	815	815	815	815	815	815	815	815	815
	Reclining Angle	backward reclining angle from neutral	66°k	66°k	66°k	66°k	66°k	66°k	66°k	66°k	66°k
		forward reclining angle from neutral(b	20°w	20°w	20°w	20°w	20°w	20°w	20°w	20°w	20°w
		First lock angle from neutral(c)	10°s	10°s	10°s	10°s	10°s	10°s	10°s	10°s	10°s

* Back of AS seat with table function should be horizontal when it is folded.

2nd Seatc

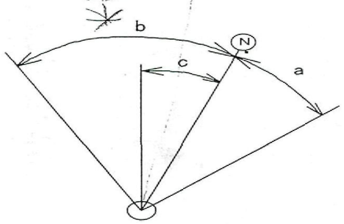
			DOM					EUR			NAM	
			RHD					RHD/LHD			LH	
			W32G [GN]	J32B C-MPV	W32C		W32E [ZR]	B32A	W32C [NR]	W32E [ZR]	L32H [HS]	deca bus
Seat Type	Back		6:4k	6:4	5:5k	Captain Seat	6:4t	6:4t	6:4	6:4t	6:4t	-
	Cush		6:4h	6:4h	5:5h		6:4t	6:4t	6:4	6:4t	6:4t	-
Core Dimension	Neutral Tolso Angle	-	25	25	22	21	25	25	25	25	25	25
	Cush Widthl	RH	800	719	650	520	800	800	800	800	800	430(each seat)
		LH	530	489	650	520	530	530	530	530	530	-
	Cush Lengtha	H.P～Cush Fr Edgegle	348	341	338	333	348	348	348	348	348	348
	Back Widthr	RH	800	738	605	446	800	800	800	800	800	430(each seat)
		LH	530	508	605	446	530	530	530	530	530	-
	Back Heighta	H.P～Back Top Edgele□	610	555	518	525	610	610		610	610	610
	H/R Heighto	H.P～Along Torso Lowest Position	765	765	765	765	765	765	765	765	765	765
		H.P～Along Torso Highest Positior	-	-	-	-	-	-	-	-	-	-
	Reclining Angle	backward reclining angle from neutral	0°c	64°k	65°k	68°k	12°k	4	64	12	0°°	65
		First lock angle from neutral(c)	-	8	8°r	8°r	8	8	8°r	8	-	8

* Forward-bend angle should be set for Back to be horizontal when it is folded for luggage space or table function.

3rd Seat

			DOM		EUR
			RHD		RHD/LHD
			J32B C-MPV	W32C [NR]	W32C [NR]
Seat Type	Back		BENCH	5:5C	5:5
	Cush		BENCH	5:5C	5:5
Core Dimension	Neutral Tolso Angle	-	21	25	21
	Cush Widthl		970	-	970
		RH	-	635	-
		LH	-	635	-
	Cush Length□	H.P～Cush Fr Edgegle	284	321	284
	Back Widthr		970	-	970
		RH	-	620	-
		LH	-	620	-
	Back Height□	H.P～Back Top Edgele□	504	469	504
	H/R Heighto	H.P～Along Torso Lowest Position	765	765	765
		H.P～Along Torso Highest Positior	-	-	-
	Reclining Angle	backward reclining angle from neutral	12°k	60°k	60°k
		forward reclining angle from neutral(b	111	115	111
		First lock angle from neutral(c)	17°s	17	17

Head rest height Requirement:To meet ECE Regulation



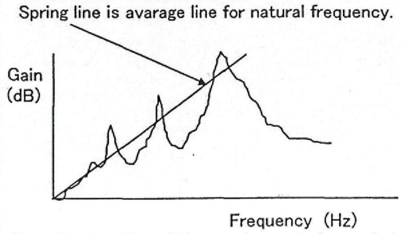
Extracts Specification Tender

Other Extract form Specification Tender

S/T No. KB1S-A003

[2] Others

4

Item		Requirement
Safety	Front Impact	・No unlock, No breakage by the condition of ODB 64km/h & Full lap 56km/h ・Dummy's waist displacement must not exceed the value of Graph 2 in the forward direction. (Under the test condition which is specified as Graph 1(G wave) with AM50 dummy.)
	Side Impact	・Regarding the sitting position of EURO-SID, LR dimension which is specified on Figure 1 must be less than 150mm incl. tolerance (Seat position – Slide : center of travel, Recliner : Neutral Lifter : center of travel.)
	Anti submarine RR seat	・RR sliding seat must have anti submarine feature.
Side Airbag deployment performance		Side Airbag Minimum deployment force is 2445.3N
Perceived Quality		・Must achieve target value for each item of the table in NDS as Table 1.
Comfort		・FR seat … Must achieve Target value as Table 2 ・RR seat … Must keep same level as current K11 ・FR&RR Headrest … Must avoid strange feeling because of the big difference of the foam hardness between headrest and seat back.
Dummy posture condition		・Must achieve the requirement as Table 3.
Reliability		・Must achieve the requirement as Table 4.
Ultraviolet ray	add add add	~~・MAX transmittance of glass is as Table 5.~~ ・Transmittance of fr windscreen is as Figure1and Figure2. ・Transmittance of doorglass increase 25% of value than that of fr windscreen.
Fuse capacity		・Heater seat : Fuse capacity of harness for vehicle side is 10A.
Logistics		・Vehicle Logistics condition : need to consider transport method by ship. Detail Condition is as NDS.
Vibration	add	・Natural frequency of seat itself must be less than 14.0Hz or more than 33.0Hz. vibration amplify ratio from spring line must be less than 10dB & Inertance must be less than 7dB. Spring line is avarage line for natural frequency.  Even if not achieved the requirement above, judge OK if no concern at actual vehicle condition. ・Must achieve above requirement not only fr seat but also rr seat.
Walk-in function add		After using walk-in function, 1)DR Seat cushion & back should return to the position where occupant used before. [full.] 2)AS Seat cushion & back should return to "neutral" position. [neutral]
Rcl operate structure add		Lever type or Dial type, Either type is OK. About the rotation ctr condition (area) shold be spec. tendered at nest timing. (11-May)

Part List

S/T No. KB1S-A003

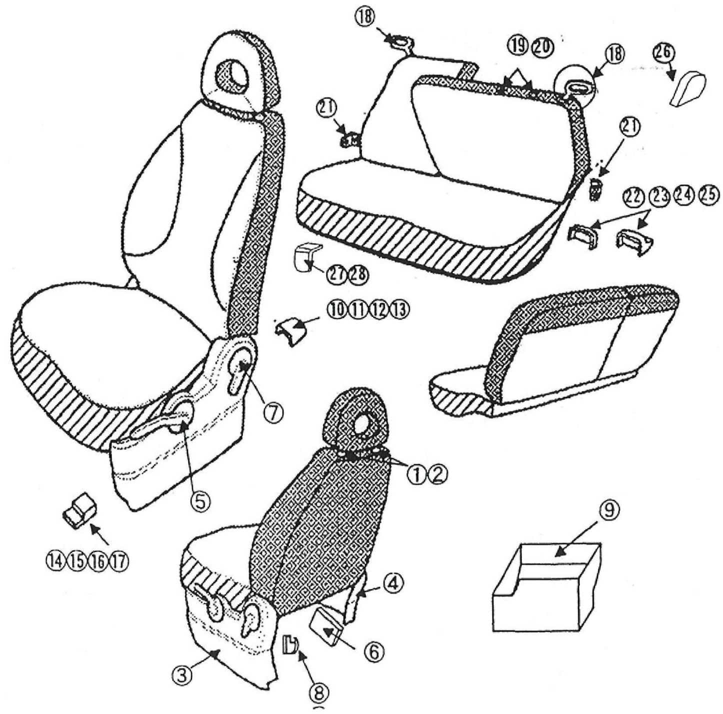
10

7 Styling

(1) Plastic Parts Colour + Grain Spec Chart

Item		Part	Grain No.	Colour Code K Creek	J Ecru	C Cinnamon
FR	1	HLDER ASSY-HRST,LOCK	#424	PK56	PJ05	PK32
	2	HLDER ASSY-HRST,FREE	↑	↑	↑	↑
	3	FIN ASSY-CUSH, FR SEAT RH/LH OTR	#545	PK55	PK32	↑
	4	FIN ASSY-CUSH, FR SEAT RH/LH INR	↑	↑	↑	↑
	5	KNOB-LIFTER LEVER RH/LH	#424	↑	↑	↑
	6	COVER-RCLNG DVC, FR SEAT RH/LH INR	↑	↑	↑	↑
	7	KNOB-RCLNG DVC LEVER,RH/LH	↑	↑	↑	↑
	8	COVER-RCLNG DVC, FR SEAT RH/LH OTR	↑	↑	↑	↑
	9	UNDER TRAY	↑	↑	↑	↑
If Required (slide fixing method TBC)	10	COVER-SEAT SLIDE RR INR RH	↑	↑	↑	↑
	11	COVER-SEAT SLIDE RR INR LH	↑	↑	↑	↑
	12	COVER-SEAT SLIDE RR OTR RH	↑	↑	↑	↑
	13	COVER-SEAT SLIDE RR OTR LH	↑	↑	↑	↑
	14	COVER-SEAT SLIDE FR INR RH	↑	↑	↑	↑
	15	COVER-SEAT SLIDE FR INR LH	↑	↑	↑	↑
	16	COVER-SEAT SLIDE FR OTR RH	↑	↑	↑	↑
	17	COVER-SEAT SLIDE FR OTR LH	↑	↑	↑	↑
RR (all)	18	KNOB-LOCK,RR SEAT BACK	#424 (*)	PK56	PJ05	↑
	19	HLDER ASSY-HRST,LOCK	↑	↑	↑	↑
	20	HLDER ASSY-HRST,FREE	↑	↑	↑	↑
If Required	21	COVER-RR SEAT HINGE BRKT,RH/LH	↑	PK55	PK32	PK32
	22	COVER-RR SEAT ISO-FIX BRKT,RH INR	↑	↑	↑	↑
	23	COVER-RR SEAT ISO-FIX BRKT,RH OTR	↑	↑	↑	↑
	24	COVER-RR SEAT ISO-FIX BRKT,LH INR	↑	↑	↑	↑
	25	COVER-RR SEAT ISO-FIX BRKT,LH OTR	↑	↑	↑	↑
RR (slide only)	26	COVER-RR SEAT HINGE BRKT,CTR	↑	PK55	PK32	PK32
	27	COVER- LEG 2ND SEAT LH INR/OTR	↑	↑	↑	↑
	28	COVER- LEG 2ND SEAT LH INR/OTR	↑	↑	↑	↑

(*) No. 18 - if carry over part then grain type can be discussed



APPENDIX D CASE STUDY 1: The SEATING SYSTEM

Cost Estimation Rules for the Seating System

Rule 1: Tooling cost for foam

Tooling Rules

Tooling cost for foam

If pre-production stage = Trial Part (PT1)

Then **Resin Tool**

    If volume <= 150

        If resin tool usage is < 150

            Then Cost of tool modification = €1,500

            And cost on piece is (1,500/150) = **€10.00**,

        Else (New Resin tool required)

            Then Cost of new Resin tool = 30,000

            And cost on piece is (30,000/150) = **€200.00**

Else

If production stage = Pre-production (PT2)

Then **Development Tool**

    If volume <= 100,000

        If wall thickness >= 6mm

            Then Cost of tool modification = €8,000

            And cost on piece is (8,000/100,000) = **€0.80**,

        Else (New Development tool required)

            Then Cost of new Development tool = 100,000

            And cost on piece is (100,000/100,000) = **€1.00**.

Else

If production stage = SOP

Then **Production Tool**

    If volume <= 100,000

        If wall thickness >= 6mm

            Then Cost of tool modification = €10,000

            And cost on piece is (10,000/100,000) = **€0.10**,

        Else (New Production tool required)

            Then Cost of new Production tool = 200,000

            And cost on piece is (200,000/100,000) = **€2.00**.

Data required:

- Production stage
- Required volume of parts
- Various types of tool and cost
- Cost of each type of tool modification

Rule 2: Tooling cost for frame

Tooling Rules

Tooling cost for frame

If part = **Small**

If 'can tool be modified' = yes

Then modify tooling cost = €10,000

And cost on piece is (10,000/100,000) = **€0.10**

Else (New tool required)

Then new tooling cost = €100,000

And cost on piece is (100,000/100,000) = **€1.00**

If part = **Medium**

If 'can tool be modified' = yes

Then modify tooling cost = €15,000

And cost on piece is (15,000/100,000) = **€0.15**,

Else (New tool required)

Then new tooling cost = 150,000

And cost on piece is (150,000/100,000) = **€1.50**

If part = **Large**

If 'can tool be modified' = yes

Then modify tooling cost = €20,000

And cost on piece is (20,000/100,000) = **€0.20**,

Else (New tool required)

Then new tooling cost = 200,000

And cost on piece is (200,000/100,000) = **€2.00**

Data Required:

- Size of part
- Tool capacity 100,000 piece

Rule 3: Tooling cost for fabric

This looks more like machinery and not tooling. Therefore, it is recovered in the overhead minute rate

Tooling Rules

Tooling cost for fabric

There is only one cost for the sewing machine. Approximately €500,000

The sewing machine can be used to sew any part size

#. What is the size part?
    If the size is small
        Then
            If straight line sewing cost €0.50
        Else
            If mixed line sewing cost €1.00
        Else
            If curve line sewing cost €1.50
    If the size is medium
        Then
            If straight line sewing cost €1.00
        Else
            If mixed line sewing cost €1.50
        Else
            If curve line sewing cost €2.00
    If the size is large
        Then
            If straight line sewing cost €1.50
        Else
            If mixed line sewing cost €2.00
        Else
            If curve line sewing cost €3.00

Data required:
    Sewing machine
    Size of part
    Type of sewing (straight, mixed or curve)

Rule 4: Raw Material cost for foam

Raw Material foam

#. What type of part?
If the foam is purchased locally
    If the size is small
        Cost is €1.50
 	
    Else if the size is medium
        Cost is €2.00
 	
    Else if the size is large
        Cost is €2.50
 	
Else (from abroad)
    If the size is small
        Cost is €2.00
 	
    Else if the size is medium
        Cost is €2.50
 	
    Else if the size is large
        Cost is €3.00
 	
NB : Time to deliver from abroad maybe an issue

Data required:

- Raw material
- Size of part

Rule 5: Raw Material cost for frame

Material Metal

#. What type of part?
If the metal is purchased locally
    If the size is small
        Cost is €2.00

    Else if the size is medium
        Cost is €2.50

    Else if the size is large
        Cost is €3.00
Else (from abroad)
    If the size is small
        Cost is €2.50

    Else if the size is medium
        Cost is €3.00

    Else if the size is large
        Cost is €3.50

NB: Time to deliver from abroad maybe an issue

Data required:
- Carry over nesting
- Metal sheet
- Size of part

Rule 6: Raw Material cost for fabric

Material Fabric

#. What type of part?
If the fabric is purchased locally
    If the size is small
        Cost is €0.50

    Else if the size is medium
        Cost is €1.00

    Else if the size is large
        Cost is €1.50
Else (from abroad)
    If the size is small
        Cost is €1.00

    Else if the size is medium
        Cost is €1.50

    Else if the size is large
        Cost is €2.00

NB: Time to deliver from abroad maybe an issue

Data required:
- Nesting of carry over
- Fabric roll
- Size of part

Rule 7: Labour cost for foam
Skill rate is usually AB (semi skilled). Can be AA or AC and not AS

Labour on foam

#. Skill required and what type of part?
  If skill required is unskilled
    If the size is small
      Cost is €0.50

    Else if the size is medium
      Cost is €0.75

    Else if the size is large
      Cost is €1.00

NB: AB is the only level of skill required

Data required:
- Time variance for part production (cycle time)
- Size of part to produce
- Labour rate

Rule 8: Labour cost for frame

Labour on metal

#. Skill required and what type of part?
  If skill required is unskilled
    If the size is small
      Cost is €1.00

    Else if the size is medium
      Cost is €1.50

    Else if the size is large
      Cost is €2.00

NB: AB is the only level of skill required

Data required:
- Time to produce parts
- Size of part to produce
- Rate

Rule 9: Labour cost for fabric

Labour on fabric

#. Skill required and what type of part?

If skill required is unskilled

If the size is small

Cost is €0.50

Else if the size is medium

Cost is €0.75

Else if the size is large

Cost is €1.00

NB: AB is the only level of skill required

Data required:

Time to produce parts
Size of part to produce
Rate

Rule 10: Machinery cost for foam

Machinery on foam

#. What is the size of the part?

If the size is small

Cost is €2.00

Else if the size is medium

Cost is €2.67

Else if the size is large

Cost is €4.00

Data required:

Size of part to produce

Rule 11: Machinery cost for frame

Machinery on frame

#. What is the size of the part?

If the size is small

Cost is €1.25

Else if the size is medium

Cost is €1.25

Else if the size is large

Cost is €1.25

Data required:

Size of part to produce

Rule 12: Machinery cost for fabric

Machinery on fabric

#. What is the size of the part?

If the size is small

Cost is €1.25

Else if the size is medium

Cost is €1.25

Else if the size is large

Cost is €1.25

Data required:

Size of part to produce

Rule 13: Bought-out-items cost for plastic parts and cast parts

Bought-out items

#. What type of item is required?
Get new quote from tier 2 supplier or exact cost on old estimate.

Time Estimation Rules for the Seating System

Rule 1: Tooling time for foam

Tooling Rules

Tooling time for foam

If production stage = Trial Part (PT1)
Then **Resin Tool**
  If volume <= 150
    If resin tool usage is < 150
      Then time for tool modification = 2 weeks
    Else (New Resin tool required)
      Then time for new Resin tool = 4 weeks
Else
If production stage = Pre-production (PT2)
Then **Development Tool**
  If volume <= 100,000
    If wall thickness >= 6mm
      Then time for tool modification = 4 weeks
    Else (New Development tool required)
      Then time for new Development tool = 8 weeks
Else
If production stage = SOP
Then **Production Tool**
  If volume <= 100,000
    If wall thickness >= 6mm
      Then time for tool modification = 5 weeks
    Else (New Production tool required)
      Then time for new Production tool = 10 weeks

Data required:
- Production stage
- Required volume of parts
- Various types of tool and time
- Time for each type of tool modification
- This should include validation of the tool

Rule 2: Tooling time for frame

Tooling Rules

Tooling time for frame

If part = **Small**
    If 'can tool be modified' = yes
        Then tooling time = 5 weeks
    Else (New metal press required)
        Then tooling time = 10 weeks

If part = **Medium**
    If 'can tool be modified' = yes
        Then tooling time = 10 weeks
    Else (New metal press required)
        Then tooling time = 18 weeks

If part = **Large**
    If 'can tool be modified' = yes
        Then tooling time = 16 weeks
    Else (New metal press required)
        Then tooling time = 32 weeks

Data Required:
- Metal press
- Size of part
- Tool capacity 100,000 piece
- Time includes validation by OEM

Rule 3: Tooling time for fabric

Tooling Rules

Tooling time for fabric

The sew machine can sew any fabric size

#. What is the size part?
    If the size is small
        Then
            If straight line sewing time 10 seconds
        Else
            If mixed line sewing time 20 seconds
        Else
            If curve line sewing time 25 seconds
    If the size is medium
        Then
            If straight line sewing time 30 seconds
        Else
            If mixed line sewing time 50 seconds
        Else
            If curve line sewing time 60 seconds
    If the size is large
        Then
            If straight line sewing time 50 seconds
        Else
            If mixed line sewing time 80 seconds
        Else
            If curve line sewing time 90 seconds

Data required:
- Sewing machine
- Size of part
- Type of sewing (straight, mixed or curve)
- Validation is not done for sewing but for the final product

Rule 4, 5 and 6: Raw Material time delivery for foam, frame and fabric

Raw Material time

#. What type of part?
If the foam is in-stock
    If the size is small
        Assume 0

    Else if the size is medium
        Assume 0

    Else if the size is large
        Assume 0

Else If the foam is purchased locally (assumes new supplier of raw materials)
    If the size is small
        Time is 2 week

    Else if the size is medium
        Time is 2 week

    Else if the size is large
        Time is 2 week

Else (from abroad)
    If the size is small
        Time is 4 weeks

    Else if the size is medium
        Time is 4 weeks

    Else if the size is large
        Time is 4 weeks

Data required:
- Raw material
- Metal sheet
- Fabric roll
- Size of part

Rule 7: Labour time for foam

Labour on foam

#. What type of part?

If the size is small

Time is 60 seconds

Else if the size is medium

Time is 90 seconds

Else if the size is large

Time is 100 seconds

NB: total capacity is 100,000

NB: total cycle time

Data required:

Cycle time (Time to produce parts)

Size of part to produce

Labour rate

Rule 8: Labour time for frame

Labour on frame

#. What type of part?

If the size is small

Time is 60 seconds

Else if the size is medium

Time is 80 seconds

Else if the size is large

Time is 100 seconds

NB: total capacity is 100,000

NB: total cycle time

Data required:

Cycle time (Time to produce parts)

Size of part to produce

Labour rate

Rule 9: Labour time for fabric

Labour on fabric
#. What type of part? If the size is small Time is 150 seconds Else if the size is medium Time is 180 seconds Else if the size is large Time is 210 seconds NB: total capacity is 100,000 NB: total cycle time

Data required:

Cycle time (Time to produce parts)
Size of part to produce
Labour rate

Rule 10: Machinery time for foam

Machinery on foam
#. What type of part? If the size is small Time is 18 months Else if the size is medium Time is 18 months Else if the size is large Time is 18 months NB: total capacity is 100,000 NB: total cycle time

Data required:

Cycle time (Time to produce parts)
Size of part to produce
Labour rate

Rule 11: Machinery time for frame

Machinery on frame

#. What type of part?

If the size is small
Time is 6 months

Else if the size is medium
Time is 6 months

Else if the size is large
Time is 6 months

NB: total capacity is 100,000
NB: total cycle time

Data required:

Cycle time (Time to produce parts)
Size of part to produce
Labour rate

Rule 12: Machinery time for fabric

Machinery on fabric

#. What type of part?

If the size is small
Time is 1 week

Else if the size is medium
Time is 1 week

Else if the size is large
Time is 1 week

NB: total capacity is 100,000
NB: total cycle time

Data required:

Cycle time (Time to produce parts)
Size of part to produce
Labour rate

Rule 13: Bought-out-items time for plastic parts

Bought-out items

#. What type of item is required?

Delivery usually takes 2 weeks

External Cost Impact Analysis Rules for the Seating System

External components affected

1. Body-in-white (headrest, rail)
2. Interior-trim (headrest, backrest, armrest, cushion)
3. Dashboard (backrest, armrest, cushion)
4. POI – point of impact

If change origin is headrest
    If body-in-white is affected
        Then POI is roof panel, cost is **€50.00**

    Else if interior-trim is affected
        Then POI is interior fabric, cost is **€225.00**

If change origin is rail
    If body-in-white is affected
        Then POI is floor panel, cost is **€50.00**

    Else if interior-trim is affected
        Then POI is interior fabric, cost is **€225.00**

If change origin is backrest
    If interior-trim is affected
        Then POI is interior fabric, cost is **€225.00**

    Else if dashboard is affected
        Then POI is steering wheel and instrument panel, cost is **€100.00**

If change origin is armrest
    If interior-trim is affected
        Then POI is interior fabric, cost is **€225.00**

    Else if dashboard is affected
        Then POI is steering wheel and instrument panel, cost is **€100.00**

If change origin is cushion
    If interior-trim is affected
        Then POI is interior fabric, cost is **€225.00**

    Else if dashboard is affected
        Then POI is steering wheel and instrument panel, cost is **€100.00**

APPENDIX E SAMPLE COOLING SYSTEM DOCUMENTS

Dimension Tables (DIN Standard)

Page 5
DIN 3021-3

Table 1: Dimensions spring band clamp/hose/spigot

Dimensions in millimetres

Spring band clamp nominal diameter d_n	Spring band clamp minimal functional diameter d_f	Hose internal diameter d_i	Hose internal diameter limit dimens.	Hose wall thickness p	Spigot external diameter d_s	Spigot external diameter limit dimens	Spigot bead diameter d_w	Spigot bead diameter limit dimens	f+1	x	L_{mn} c=12	L_{mn} c=1
13	12,7	6,5			6,5		7,3					
14	13,7	8			8		9					
15	14,7	8,5			8,5		9,6					
16	15,7	9,5			9,5		10,7					
17	16,3	10			10		11,2					
18	17,3	11			11		12,3		4,0			
19	18,3	12			12		13,5					
20	19,3	13			13		14,6	0		0,15		
21	20,3	14			14	± 0,2	15,7	- 0,25				
22	21,3	15	-0,5	3,5± 0,4	15		16,8					
23	22,3	16	-1		16		18,0					
24	23,3	17			17		19,1					2:
25	24	18			18		20,2					
26	25	19			19		21,3					
27	26	20			20		22,4					
28	27	21			21		23,5					
29	28	22			22		24,5					
30	29	23			23		25,5					
32	31	25			25		27,5		6			
34	33	26			26		28,5					
35	34	27			27		29,5				20	
36	35	28			28		30,5			0,3		
38	37	30	-0,5	4± 0,5	30	± 0,3	32,5					
40	39	32	-1,3		32		34,5					
42	40,5	34			34		36,5	0				
43	41,5	35			35		37,5	- 0,5				
44	42,5	36			36		38,5					
46	44,5	37			37		39,5					
47	45,5	38			38		41					
49	47,5	40			40		43					
50	48,5	41			41		44					
51	49,5	42			42		45					
53	51,5	44			44		47					
55	53,5	46		4,5± 0,5	46		49					2
60	58,5	50			50		53		7			
65	63,5	55			55		58					
70	68,5	60			60		63	0				
75	73,5	65	-0,5		65		68	+0,5				
80	78,5	70	-1,7		70		73					
85	83,5	75			75		78					
90	88,5	80			80		83					

54.5 58.9
53.3

4·2 → 5·0

QAF (Quotation Analysis Form)

Jaguar

CONFIDENTIAL

QUOTATION ANALYSIS FORM

SUMMARY

Ref. No.:		Date:	20-Jan-05	Supplier:	
Sheets:	7	Sheet:	2	Part No.:	
Issue/Release No.:		Desc.:	TOP RAD HOSE	Code:	
Model Code:		Vol.:	22,800		

1. Procured Parts (FROM SHEET 2) — BOP Scrap Value = 0.024 — Sub Total (1) = 2.238

2. Raw Material

Desc./Type/Grade/Supplier	Country of Origin	Ex_Rate Fctr	Lcl_ Dmln	UOM	Gross Usage	Net Usage	Price per UOM	Scrap (%)	Re-claim	Mat_O/H (%)	Unit Cost
Rubber EPDM			EUR	kg	0.594	0.594	2.390	2.500		3.500	1.505
PET Yarn			EUR	kg	0.025	0.025	4.111	2.500		3.500	0.111
											0.000
											0.000
											0.000
											0.000
											0.000
											0.000

Raw Material Continuation Sheet..? No — Mat. Scrap Value = 0.038 — Sub Total (2) = 1.616

3. Process Costs

Op.	Operation	Working (Hrs./Wk.)	Heads	Actual (No./Hr.)	Dir._Lab. (Rte./Hr.)	Soc._O/H (Rte./Hr.)	Other_O/H (Rte./Hr.)	Tot._Lab. Cost	M/C (Rte./Hr.)	M/C Cost	Scrap (%)	Unit Cost
1	Extrusion & Cutting		2.00	181.100	3.50	2.35	4.38	0.113	56.00	0.309	2.50	0.433
2	Vulcanisation & Washing		1.00	18.500	3.50	2.35	4.38	0.553	15.00	0.811	2.50	1.398
3	Assembly & Markation		1.00	10.900	3.50	2.35	4.38	0.938	3.00	0.275	2.50	1.244

Process Costs Continuation Sheet..? No — Op. Scrap Value = 0.075 — Sub Total (3) = 3.075

Local Content :	
Price :	
Forex Content :	
Price :	
Total Price:	

Assumptions:

TOTAL MANUFACTURING COST (1) + (2) + (3): 6.928

4. Other Costs — Enter Calculations...

		Unit Cost
General Overheads:	9.00%	0.797
Design & Development:	4.00%	0.354
Other Costs..? (FSS):	2.00%	0.177
Profit:	5.00%	0.443

25% on TMC

Sub Total (4) = 1.770

5. Tooling Costs (FROM SHEET 5) — Sub Total (5) = 50,995

Tooling Cost per Part Included in Piece Price =

TOTAL PART COST (1) + (2) + (3) + (4) + (5): 8.698

Capable Volume	
Base Material	per
Production Location	
Working Days per Year	
Component Weight	
Delivered Quality (PPM)	
INCO & Duty	
Quoted Currency	EUR
Exchange Rate	

6. Logistics Costs

Transport + Sequencing + Warehousing (Supplier only)	
Packaging	0.150
Pallet Maintenance	

Logistics QAF..? No — Sub Total (6) = 0.150

Signed Supplier:

Date:

TOTAL OFFER PRICE (1) + (2) + (3) + (4) + (5) + (6): 8.85

 PAG QAF Vers. 2 - 05 Apr 2001 QAFREFNO1.SUPPLIER

Product Design Specification (a)

- IN STRICT CONFIDENCE -

DOC. REF: ISSUE NO: ONE DATE: Page 11 of 51 VPG: CV

SECTION 6: PERFORMANCE

6.3.4.2 Coolant Circuit Susceptibility to **Cavitation Flow Reduction**

The system must accommodate operation to the maximum coolant temperature without significant loss of performance due to loss of coolant flow caused by cavitation near the system boiling point.

In other words, the system must not exhibit a runaway condition as it approaches boiling point.

FR

6.3.4.3 Coolant Circuit **Flow Resistance**

Radiator resistance to coolant flow must be compatible with the planned engine.

*?

6.3.5 Coolant Circuit Assembly Line Fill Procedure

Refer to section 18: Manufacturing Requirements

6.3.6 Coolant Circuit Service Drain and Fill Procedure

The coolant circuit shall be designed such that when the recommended service fill procedure is adopted, it is able to bleed any gaseous fluid from the system to the expansion tank during one fill and warm-up cycle only. Further, this should be the performance objective for a system filled without regard to a recommended service fill procedure.

FR

The service fill should have the following attributes:

Easy to drain (Heater, Engine, Radiator)

3 sub FRs

- The drain points must be accessible, with space sufficient to remove hose clips and hoses if a drain tap is not fitted.
- Coolant should be easy to collect in a tray and not contaminate the operator.
- The system should drain continuously without an unexpected surge, and should drain sufficient fluid to avoid contamination of the fresh charge. The advice of the antifreeze supplier should be sought.
- Bleed points should not have to be opened to assist the drain process. Also see requirements for end of life fluid drain (9.2.2). ? Missing

Fast Fill

FR FR

The complete procedure should take no longer than 5 minutes including any engine running time. No road test should be required. It should be simple to fill without causing spillage on the floor, and any local spillage on the bodywork should be easy to clean.

Reliable

4FR

The fill process should not be sensitive to procedure or vehicle attitude. The fill should proceed without hesitation and it should be obvious when the process is complete. This infers that there should be no periods in which the level in the expansion tank is not subsiding visibly or bubbling out air. There must be no significant drop in the expansion tank level during customer use after this process.

Runaway Condition ?

11

Product Design Specification (b)

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DOC. REF: **ISSUE NO:** ONE **DATE:** **VPG:** CV

SECTION 7: ERGONOMICS

7.1 COOLANT LEVEL ASSESSMENT

FR The system should be such that an under bonnet check of coolant level is possible without removal of the tank cap.

7.2 COOLANT TOP UP

FR Coolant top up should be simple, safe, and clean for 5th to 95th percentile people, without need for tools or special containers.

17

BOM (Bill of Materials)

OPS$ZMOYO3

GBOM-Group Bill of Material-Land Rover
Item Explosion

Page 4 of 22
13-JAN-05

L	Item	Ford Item No	Description	Qty	Eff From	Eff To	C/O From	C/O To	Prod	A	Con	Cons	Sign
1	TFCV256L322		V8 PETROL NA 06MY	1	17-11-2003		511196/001/001						
1					17-11-2003		511196/001/001		SLA5	M	L	SLA5	
2	CVCE256		EXPANSION TANK AJV8 06MY	1	17-11-2003		511196/001/001						
2					17-11-2003		511196/001/001		SLA5	M	M	SLA5	
3	572312	1H1Z- 8A297-AA	GROMMET	1	31-01-2005		521427/001/001						
3					31-01-2005		521427/001/001		SLA5	B	A	SLA5	
3	PCD000090	5H2Z- 8K103-AA	CAP-EXPANSION TANK PRESSURE	1	17-11-2003		511196/001/001						
3					17-11-2003		511196/001/001		SLA5	B	A	SLA5	
4	INST051		INSTRUCTION 051	0	25-08-2003	13-10-2003	506491/001/001	515710/001/001					
4					25-08-2003	13-10-2003	506491/001/001	515710/001/001	SLV1	H	X	SLV1	
4	INST075		INSTRUCTION 075	0	13-10-2003		515710/001/001						
4					13-10-2003		515710/001/001		SLV1	H	X	SLV1	
3	PCF500040		TANK-RADIATOR EXPANSION	1	17-11-2003	18-10-2004	511196/001/001	518366/001/001					
3					17-11-2003	18-10-2004	511196/001/001	518366/001/001	SLA5	B	A	SLA5	
3	PCF500050	6H42- 8A080-AA	TANK-RADIATOR EXPANSION	1	18-10-2004		518366/001/001						
3					18-10-2004		518366/001/001		SLA5	B	A	SLA5	
3	PCU500070		BRACKET ASSY-EXPANSION TANK	1	17-11-2003	09-02-2004	511196/001/001	516552/001/001					
3					17-11-2003	09-02-2004	511196/001/001	516552/001/001	SLA5	B	A	SLA5	
3	PCU500100		BRACKET ASSY-EXPANSION TANK	1	09-02-2004	18-10-2004	516552/001/001	518366/001/001					
3					09-02-2004	18-10-2004	516552/001/001	518366/001/001	SLA5	B	A	SLA5	
3	PCU500110		BRACKET-EXPANSION TANK	1	18-10-2004	18-10-2004	518366/001/001	517392/003/001					
3					18-10-2004	18-10-2004	518366/001/001	517392/003/001	SLA5	B	A	SLA5	
3	PCU500190	6H42- 8B082-BA	BRACKET ASSY-EXPANSION TANK	1	18-10-2004		517392/003/001						
3					18-10-2004		517392/003/001		SLA5	B	A	SLA5	
3	PYA000010	1H4Z-PYA00001-0	GROMMET	1	09-02-2004	31-01-2005	516668/001/001	521427/001/001					
3					09-02-2004	31-01-2005	516668/001/001	521427/001/001	SLA5	B	A	SLA5	
3	PYP500040	- W503924-S301	SCREW-DOG POINT	5	17-11-2003	18-10-2004	511196/001/001	518366/001/001					
3					17-11-2003	18-10-2004	511196/001/001	518366/001/001	SLA5	B	A	SLA5	
3	PYP500040	- W503924-S301	SCREW-DOG POINT	5	18-10-2004		518366/001/001						
3					18-10-2004		518366/001/001		SLA5	B	A	SLA5	

LAND ROVER IN STRICT CONFI[illegible]CE

OPS$ZMOYO3

GBOM-Group Bill of Material-Land Rover
Item Explosion

Page 2 of 22
13-JAN-05

L	Item	Ford Item No	Description	Qty	Eff From	Eff To	C/O From	C/O To	Prod	A	Con	Cons	Sign
1	LCCCV256L322		V8 PETROL NA 06MY	1	17-11-2003		511196/001/001						
1					17-11-2003		511196/001/001		SLW5	M	L	SLW5	
2	CVEF256		ENGINE FAN AJV8NA 06MY	1	17-11-2003		511196/001/001						
2					17-11-2003		511196/001/001		SLW5	M	M	SLW5	
3	PGG500161	5H22- 8600-AA	FAN ASSEMBLY-COOLING	1	17-11-2003	18-10-2004	511196/001/001	519197/001/001					
3					17-11-2003	18-10-2004	511196/001/001	519197/001/001	SLW5	B	A	SLW5	
3	PGG500260	5H22- 8600-EA	FAN ASSEMBLY-COOLING	1	18-10-2004		519197/001/001						
3					18-10-2004		519197/001/001		SLW5	B	A	SLW5	
2	CVTP256		TRANS OIL PIPES AJV8 06MY	1	17-11-2003		511196/001/001						
2					17-11-2003		511196/001/001		SLW5	M	M	SLW5	
3	FS106127	4H5Z- 0614-AA	BOLT	1	17-11-2003	17-05-2004	511196/001/001	517900/001/001					
3					17-11-2003	17-05-2004	511196/001/001	517900/001/001	SLW5	B	A	SLW5	
3	FS106127	4H5Z- 0614-AA	BOLT	1	17-05-2004		517900/001/001						
3					17-05-2004		517900/001/001		SLW5	B	A	SLW5	
3	FS108167	1H4Z-FS108167-	SCREW	1	17-11-2003	17-05-2004	511196/001/001	517900/001/001					
3					17-11-2003	17-05-2004	511196/001/001	517900/001/001	SLW5	B	A	SLW5	
3	FS108167	1H4Z-FS108167-	SCREW	1	17-05-2004		517900/001/001						
3					17-05-2004		517900/001/001		SLW5	B	A	SLW5	
3	UBP500170		PIPE-OIL COOLER TO TRANSMISSION	1	17-11-2003	09-02-2004	511196/001/001	516855/001/001					
3					17-11-2003	09-02-2004	511196/001/001	516855/001/001	SLW5	B	A	SLW5	
4	UBP500180		PIPE-TRANSMISSION TO OIL COOLER	1	17-11-2003	09-02-2004	511196/001/001						
4					17-11-2003	09-02-2004	511196/001/001	516855/001/001	SLW5	D	D	SLW5	
4	UBP500190		PIPE ASSY-OIL COOLER TO TRANSMISSION	1	17-11-2003	09-02-2004	511196/001/001						
4					17-11-2003	09-02-2004	511196/001/001	516855/001/001	SLW5	D	D	SLW5	
4	UBU500050	5H2Z- 7B147-AA	BRACKET-OIL PIPE MOUNTING	1	17-11-2003	09-02-2004	511196/001/001						
4					17-11-2003	09-02-2004	511196/001/001	516855/001/001	SLW5	D	D	SLW5	
4	UBU500080	5H2Z- 7B147-CA	BRACKET-OIL PIPE MOUNTING	1	17-11-2003	09-02-2004	511196/001/001						
4					17-11-2003	09-02-2004	511196/001/001	516855/001/001	SLW5	D	D	SLW5	
3	UBP500230		PIPE ASSY-TRANSMISSION COOLING	1	09-02-2004	17-05-2004	516855/001/001	517900/001/001					
3					09-02-2004	17-05-2004	516855/001/001	517900/001/001	SLW5	B	A	SLW5	

LAND ROVER IN STRICT CONFID[illegible]CE

Functional Specification (a)

7.2.3.3.Extrusion Machine Lineup Cost per Piece

=extrusion std_mins * (extrude_core overhead_rate
+ Extrude__inner Overhead_rate
+ Knit__reinforcement Overhead_rate
+ Extrude__cover Overhead_rate
+ Print_Wheel Overhead_rate
+ Cut__green Overhead_rate)

7.2.3.4.Total Machine Mfg. overhead rate Cost/pc:

= Inner_Liner_Material_Cost_per_Piece
+Inner_material_cost_per_piece
+ cover_material_cost_per_piece
+Reinforcement_cost_per_piece

D R A F T

7.2.3.5. Extrusion Line Operators

= Extrude__core Operators. + Extrude__inner Operators.
+ Knit__reinforcement Operators. + Extrude__cover Operators
+ Print_Wheel Operators. + Cut__green Operators.

7.2.3.6.Mixing Operator Cost per Piece

= Mix_Mill Opers. * Mix_and_Mill_std_mins *
Mix_Mill Labour_rate

7.2.3.7.Extrusion Line Operator Cost per Piece

=(Extrude__core Operators * Extrude__core_std_mins * Extrude__core Labour_rate)
+ (Extrude__inner Operators * Extrude__inner_std_mins * Extrude__inner Labour_rate)
+ (Knit__reinforcement Operators * Knit_std_mins * Knit__reinforcement Labour_rate)
+ (Extrude__cover Operators * Extrude__cover_std_mins * Extrude__cover Labour_rate)
+ (Print_Wheel Operators * Print_Wheel_std_mins * Print_Wheel Labour_rate)
+ (Cut__green Operators * Cut_std_mins * Cut__green Labour_rate)

7.3. Hose Forming:

7.3.1. Application Type List

Extrude

- Load Hose to Mandrel
- Cure Hose in Oven
- Unload Hose from Mandrel
- Trim Hose to Finished Length

Labour – Process
Tool Machinery

Functional Specification (b)

D R A F T

1. References

Table 1-1 :Reference Documents

Ref. No.	Name	Title	Ver. No.
1	Rubber Hose Functional Specification	hs-fs.doc	1.6
2	Rubber Hose **One Estimate Window** Functional Specification	hs-1ew.xls	1.3
3	Rubber Hose **EXTRUSION** Functional Specification	hs-ex-fs.doc	1.3
4	Rubber Hose **UI** Functional Specification	hs-ui-fs.doc	1.5
5	Rubber Hose Excel **Protoype**	hs-proto.xls	1.2
6	Rubber Hose **Acceptance Test Plan**	hs-atp.doc	1.3
7	Rubber Injection Moulding Functional Specification	cm-rub-im-func-spec	1.18

2. Introduction

This is the Functional Specification for the Low Pressure Rubber Hose cost model. It uses an In-Line Extrusion process as the overall best-in class though there are instances where this is not true, particularly for small ID hoses. In this case cost difference is small and the estimator will have the option of using Clean sheet for an off-line process. The module addresses only one type of hose assembly through the use of the nylon jacketed injection moulding process with a three port tee assumption. Other methods of branching hoses must be addressed through clean sheet. Because of the wide variety of clamps available, the user will specify the clamps outside this expert module, then specify the number of clamps to be used in the hose module. Therefore this module will assemble the required clamps to the hose, but will not specify the purchased cost of the clamp.

2.1. Terms of Reference

ID - Inner Diameter of hose.

OD - Outer Diameter of hose.

Greenlength - Finished length of hose + additions for cutting/capping ends.

Rubber Material Specifications

Hose/Inner Material - Represents whole hose if this is the only material given, else inner layer of a hose.

Cover Material - Represents outer layer of a hose. Inputting a cover material indicates that a second extruder is required.

Liner Material - Represents the typically thin walled liner, used on the

APPENDIX F CASE STUDY 2 THE COOLING SYSTEM

Cost Estimation Rules for the Cooling System

Rule 1: Raw material cost for metal

If the part is radiator/condenser
Number of fins 50
Number of tubes 10
Aluminium sheet area (50*10) = 500
Cost of aluminium per cm^2 is €0.02
Then cost is (500*0.02) = **€10.00**

Else if the part is pipe
Length of pipe 30cm
Radius of pipe 2cm
Metal sheet area (30*2) = 60
Cost of metal per cm^2 is €0.10
Then cost is (60*0.10) = **€6.00**

Else if the part is frame
Then cost is **€1.5**

Data required:
- Type of part
- Number of fins
- Number of tubes
- Cost of aluminium per cm^2
- Length of pipe
- Radius of pipe
- Cost of metal per cm^2

Rule 2: Raw material cost for rubber

If the part is hose
Length of hose 30cm
Radius of hose 2cm
Volume 30*2 = 60
Cost of metal per cm^2 is €0.05
Then cost is (60*0.05) = **€3.00**

Data required:
- Type of part
- Length of hose
- Radius of hose
- Cost of raw material per cm^2

Rule 3: Raw material cost for plastic

If the part is thermostat housing
Then cost is **€0.50**

Else if the part is cowl
Then cost is **€1.25**

Data required:
- Type of part

Rule 4 Tooling cost for metal

> If the part is radiator/condenser
> Oven rack (1,000/25k) = 40
> Mould tool (1,000/25k) = 40
> Forming tool (1,000/25k) = 40
> Assemble tool (1,000/25k) = 40
> Multiplier is 0.05
> Then cost is (160*0.05) = **€8.00**
>
> Else if the part is pipe
> Mandrel (1,000/25k) =40
> Multiplier is 0.75
> Then cost is (40*10) = **€3.00**
>
> Else if the part is frame
> Then cost is **€2.00**

Data required:

- Type of part
- Capacity (number of car to be made)
- Cost of oven rack
- Cost of mould tool
- Cost of forming tool
- Cost of assemble tool
- Cost of mandrel

Rule 5: Tooling cost for plastic

> If the part is thermostat housing
> Mould tool (1,000/25k) = 40
> Multiplier is 0.10
> Then cost is **€2.50**
>
> Else if the part is cowl
> Mould tool (1,000/25k) = 40
> Multiplier is 0.80
> Then cost is **€2.00**

Data required:

- Type of part
- Capacity (number of car to be made)
- Cost of mould tool for thermostat
- Cost of mould tool cowl

Rule 6: Tooling cost for rubber

If the part is hose
    Mandrel cost is **€0.50**

Data required:

- Type of part
- Number of bends on hose (for each bend 50cents is incurred)

Rule 7, 8 and 9: Labour cost for metal, rubber and plastic

If the part is radiator/condenser
    Then cost is = **€15.00**

Else if the part is hose/pipe
    Then cost is **€0.60**

Else if the part is frame
    Then cost is **€3.25**

Else if the part is thermostat housing
    Then cost is **€3.50**

Else if the part is fan cowl
    Then cost is **€3.50**

Data required:

- Type of part

Rule 10: Machinery cost for metal

If the part is radiator
Oven (1,000/25k) = 40
Finisher (1,000/25k) = 40
Injection mould (1,000/25k) = 40
Multiplier is 0.20
Then cost is **€2.40**

Else if the part is pipe
Oven (1,000/25k) = 40
Multiplier is 0.07
Then cost is **€2.80**

Else if the part is frame
Then cost is **€2.00**

Data required:

- Type of part
- Capacity (number of car to be made)
- Cost of oven
- Cost of finisher
- Cost of injection mould

Rule 11: Machinery cost for rubber

If the part is hose
Extruder
Then cost is **€1.20**

Data required:

- Type of part

Rule 12: Machinery cost for plastic

> If the part is thermostat housing
>   Injection mould (1,000/25k) = 40
>   Multiplier is 0.04
>   Then cost is **€1.60**
>
> Else if the part is cowl
>   Injection mould (1,000/25k) = 40
>   Multiplier is 0.05
>   Then cost is **€2.00**

Data required:

- Type of part
- Capacity (number of car to be made)
- Cost of injection mould for thermostat
- Cost of injection mould for cowl

Rule 13: Bought-out-items cost for plastic parts

Bought-out items

#. What type of item is required?

Get new quote from tier 2 supplier or exact cost on old estimate.

Time Estimation Rules for the Cooling System

Cooling System (Volume: 25,000)

Rule 1: Raw material time for metal

```
If part is radiator
        Number of fins
        Number of tubes
                Then time is 2 weeks

Else if part is pipe
        Length of pipe
        Diameter of pipe
                Then time is 1 week
```

Rule 2: Raw material time for rubber

```
If part is hose
        Length of hose
        Diameter of hose
                Then time is 1 week
```

Rule 3: Raw material time for plastic

```
If the part is thermostat housing
        Then time is 1 week

Else if the part is cowl
        Then time is 1 week
```

Rule 4: Tooling time for metal

If part is radiator
Oven rack
Mould tool
Forming tool
Assemble tool
Then time is 2 weeks

Else if part is pipe
Mandrel (1,000/25k)
Then time is 1 week

Rule 5: Tooling time for rubber

If part is hose
Mandrel time is 1 week

Rule 6: Tooling time for plastic

If the part is thermostat housing
Injection mould (1,000/25k)
Then cost is 1 week

Else if the part is cowl
Injection mould (1,000/25k)
Then cost is 1 week

Rule 7, 8 and 9: Labour time for metal, rubber and plastic

Labour rate is fixed per hour depending on classification and country (or region)

Labour time is usually 1 week, depending on the volume of vehicles required.

Rule 10: Machinery time for metal

If part is radiator
Oven (1,000/25k)
Finisher
Injection mould (1,000/25k)
Then time is 2 week

Else if part is pipe
Oven (1,000/25k)
Then time is 1 week

Rule 11: Machinery time for rubber

If pat is hose
Extruder
Then time is 1 week

Rule 12: Machinery time for plastic

If the part is thermostat housing
Injection mould (1,000/25k)
Then cost is 1 week

Else if the part is cowl
Injection mould (1,000/25k)
Then cost is 1 week

Rule 13: Bought-out-items time for plastic parts

Bought-out items

#. What type of item is required?

Delivery usually takes 2 weeks

External Cost Impact Analysis Rules for the Cooling System

External components affected

1. Engine (hose, radiator, water pump)
2. Body-n-white (hose, fan)
3. Grill (radiator, fan)
4. Bumper (radiator, fan)
5. POI – point of impact

Part A:

If change origin is hose
    If engine is affected
        Then POI is passageway cost is **125.00** (or hose spigot on engine)
    Else if body-in-white is affected
        Then POI is engine compartment cost is **40.00**

Part B:

If change origin is radiator
    If engine is affected
        Then POI is radiator spigot on engine cost is **125.00**
    Else if grill is affected
        Then POI is grill back cost is **50.00**
    Else if bumper is affected
        Then POI is inner bumper cost is **65.00**

Part C:

If change origin is water pump
    If engine is affected
        Then POI is engine block fluid passageway cost is **200.00**

Part D:

If change origin is fan
    If body-in-white is affected
        Then POI is engine compartment cost is **40.00**
    Else if grill is affected
        Then POI is grill back cost is **50.00**
    Else if bumper is affected
        Then POI is inner bumper cost is **65.00**

APPENDIX G e-RM SOFTWARE ARCHITECTURE

Databases (MySQL)

Tables:

Product (Prod_ID, ProdName, ProdDescrip, ProdImage)

System (ProdID, SystemID, SystemName, SystemDesrip, SyetemImage, SupplierID)

SubSystem (SystemID, SubSystemID, SubSystemName, SubSystemDesrip, SubSystemImage, SupplierID)

FunctionalRequirement (SystemID, SubSystemID, FRID, FRDescrip)

Constraints (FRID, ConstID, ConstDescrip, {Range upper to lower})

DesignParameter (FRID, DPID, DPDescrip)

CostDriver (CostDriverID, CostDriverName, CostDriverDescrip)

ProductClassification (ProdClassID, ProdClassName, ProdClassDescrip, ProdID, SystemID, SubSystemID)

DevelopmentStages (DevStageID, DevStageName, DevStageDescrip)

UserDetails (UserID, UserName, PassWord, UserDept, UserAccessLevel[1,2,3], Created, LastLogin, LastLogout)

ExtentOfImpact (ExtentID, ExtentDescrip)

Granularity (GranularityID, GranularityDescrip)

Supplier (SupplierID, SupplierName)

ListOfFR (ListOfFRID, ProdID, SystemID, SubSystemID, FRID)

ListOfDP (ListOfDPID, FRID, DPID)

ListOfConst (ListOfConstID, FRID, ConstID)

Log (LogID, UserID, StartTime, StartDate, EndTime, EndDate)

Table Definitions

```
DROP TABLE IF EXISTS `e-rm`.`constraints`;
CREATE TABLE `constraints` (
  `const_id` int(10) unsigned NOT NULL auto_increment,
```

```
  `const_descrip` char(45) NOT NULL default '',
  `fr_id` char(45) NOT NULL default '',
  PRIMARY KEY  (`const_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`costdriver`;
CREATE TABLE `costdriver` (
  `cost_driver_id` int(10) unsigned NOT NULL auto_increment,
  `cost_driver_name` varchar(45) NOT NULL default '',
  `cost_driver_descrip` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`cost_driver_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`designparameter`;
CREATE TABLE `designparameter` (
  `dp_id` int(10) unsigned NOT NULL auto_increment,
  `dp_descrip` varchar(45) NOT NULL default '',
  `fr_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`dp_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`developmentstages`;
CREATE TABLE `developmentstages` (
  `dev_stage_id` int(10) unsigned NOT NULL auto_increment,
  `dev_stage_name` varchar(45) NOT NULL default '',
  `dev_stage_descrip` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`dev_stage_id`)
) TYPE=InnoDB;
```

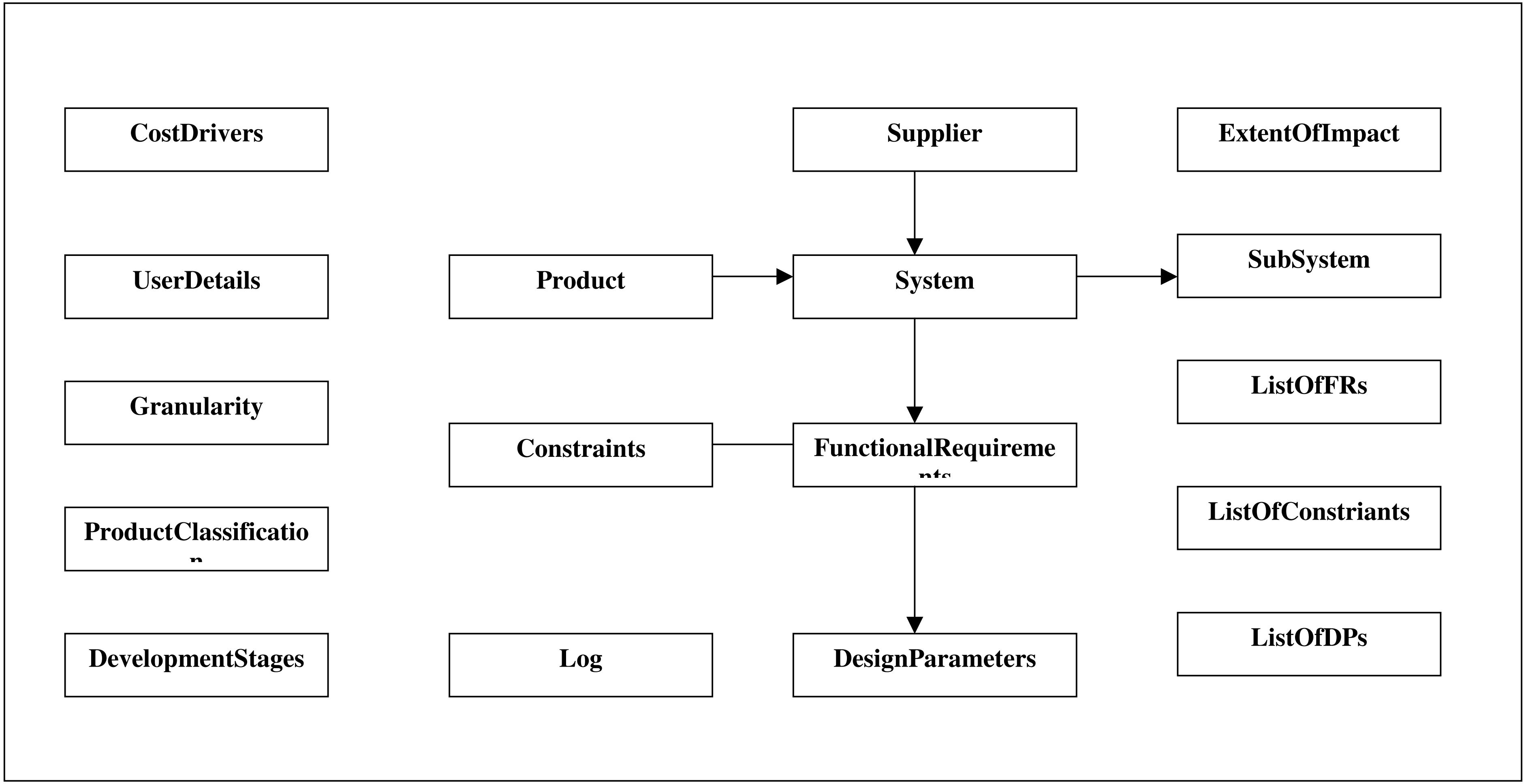
```
DROP TABLE IF EXISTS `e-rm`.`extentofimpact`;
CREATE TABLE `extentofimpact` (
  `extent_id` int(10) unsigned NOT NULL auto_increment,
  `extent_descrip` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`extent_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`functionalrequirement`;
CREATE TABLE `functionalrequirement` (
  `fr_id` int(10) unsigned NOT NULL auto_increment,
  `fr_descrip` varchar(45) NOT NULL default '',
  `system_id` varchar(45) NOT NULL default '',
  `subsystem_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`fr_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`granularity`;
CREATE TABLE `granularity` (
  `granularity_id` int(10) unsigned NOT NULL auto_increment,
  `granularity_descrip` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`granularity_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`listofconst`;
CREATE TABLE `listofconst` (
  `listofconst_id` int(10) unsigned NOT NULL auto_increment,
  `fr_id` varchar(45) NOT NULL default '',
  `const_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`listofconst_id`)
) TYPE=InnoDB;
```

```
DROP TABLE IF EXISTS `e-rm`.`listofdp`;
CREATE TABLE `listofdp` (
  `listofdp_id` int(10) unsigned NOT NULL auto_increment,
  `fr_id` varchar(45) NOT NULL default '',
  `dp_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`listofdp_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`listoffr`;
CREATE TABLE `listoffr` (
  `listoffr_id` int(10) unsigned NOT NULL auto_increment,
  `system_id` varchar(45) NOT NULL default '',
  `subsystem_id` varchar(45) NOT NULL default '',
  `fr_id` varchar(45) NOT NULL default '',
  `prod_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`listoffr_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`log`;
CREATE TABLE `log` (
  `log_id` int(10) unsigned NOT NULL auto_increment,
  `user_id` varchar(45) NOT NULL default '',
  `starttime` varchar(45) NOT NULL default '',
  `startdate` varchar(45) NOT NULL default '',
  `endtime` varchar(45) NOT NULL default '',
  `enddate` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`log_id`)
) TYPE=InnoDB;
```

```
DROP TABLE IF EXISTS `e-rm`.`product`;
CREATE TABLE `product` (
  `prod_id` int(10) unsigned NOT NULL auto_increment,
  `prod_name` char(45) NOT NULL default '',
  `prod_descrip` char(45) NOT NULL default '',
  `prod_image` char(45) NOT NULL default '',
  PRIMARY KEY  (`prod_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`productclassification`;
CREATE TABLE `productclassification` (
  `prodclass_id` int(10) unsigned NOT NULL auto_increment,
  `prodclass_name` varchar(45) NOT NULL default '',
  `prodclass_descrip` varchar(45) NOT NULL default '',
  `prod_id` varchar(45) NOT NULL default '',
  `system_id` varchar(45) NOT NULL default '',
  `subsystem_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`prodclass_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`subsystem`;
CREATE TABLE `subsystem` (
  `subsystem_id` int(10) unsigned NOT NULL auto_increment,
  `system_id` varchar(45) NOT NULL default '',
  `subsystem_name` varchar(45) NOT NULL default '',
  `subsystem_desrip` varchar(45) NOT NULL default '',
  `subsystem_image` varchar(45) NOT NULL default '',
  `supplier_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`subsystem_id`)
) TYPE=InnoDB;
```

```
DROP TABLE IF EXISTS `e-rm`.`supplier`;
CREATE TABLE `supplier` (
  `supplier_id` int(10) unsigned NOT NULL auto_increment,
  `supplier_name` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`supplier_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`system`;
CREATE TABLE `system` (
  `system_id` int(10) unsigned NOT NULL auto_increment,
  `prod_id` varchar(45) NOT NULL default '',
  `system_name` varchar(45) NOT NULL default '',
  `system_descrip` varchar(45) NOT NULL default '',
  `system_image` varchar(45) NOT NULL default '',
  `supplier_id` varchar(45) NOT NULL default '',
  PRIMARY KEY  (`system_id`,`prod_id`)
) TYPE=InnoDB;

DROP TABLE IF EXISTS `e-rm`.`userdetails`;
CREATE TABLE `userdetails` (
  `user_id` int(10) unsigned NOT NULL auto_increment,
  `lastname` char(40) NOT NULL default '',
  `firstname` char(40) NOT NULL default '',
  `username` char(16) NOT NULL default '',
  `password` char(40) binary NOT NULL default '',
  `userdept` char(20) NOT NULL default '',
  `useraccesslevel` enum('1','2','3') NOT NULL default '1',
  `deleted` enum('TRUE','FALSE') NOT NULL default 'TRUE',
  `created` timestamp(14) NOT NULL,
  `lastlogin` datetime NOT NULL default '0000-00-00 00:00:00',
  `lastlogout` datetime NOT NULL default '0000-00-00 00:00:00',
  PRIMARY KEY  (`user_id`)
) TYPE= InnoDB;
```

Entity Relationship Diagram

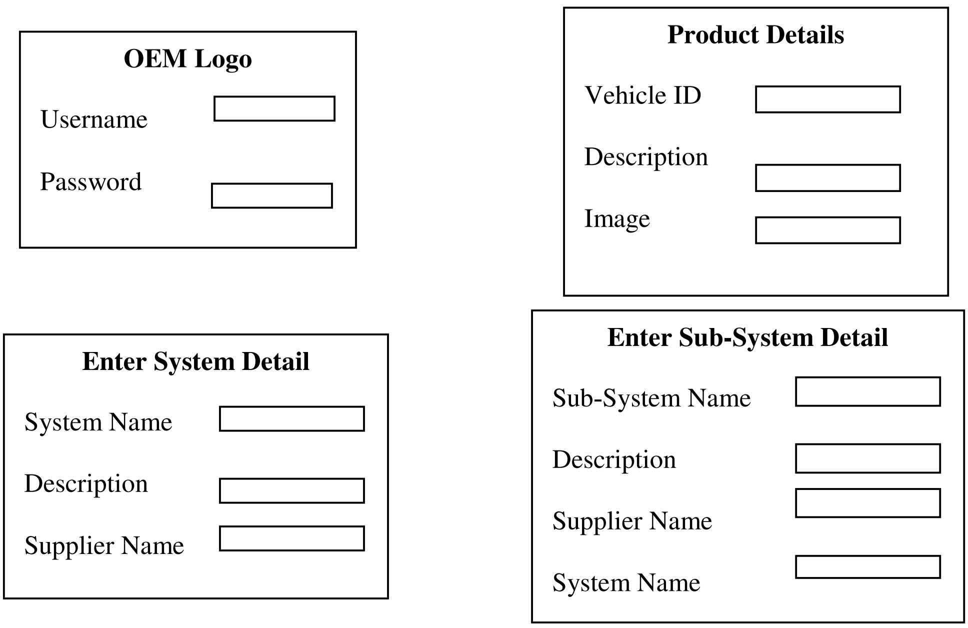


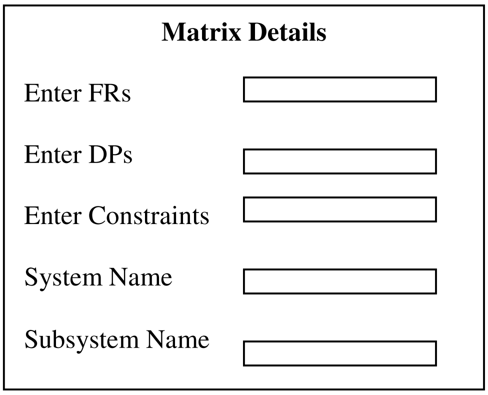
Software Requirement Analysis

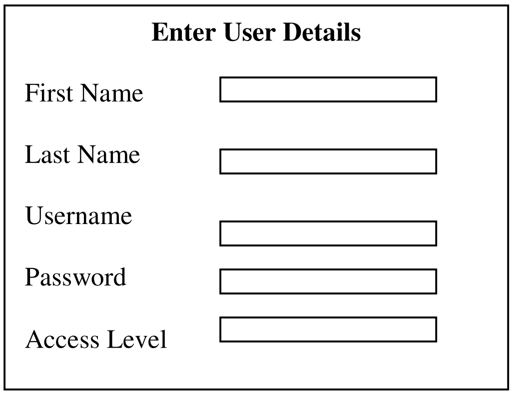
Classes:

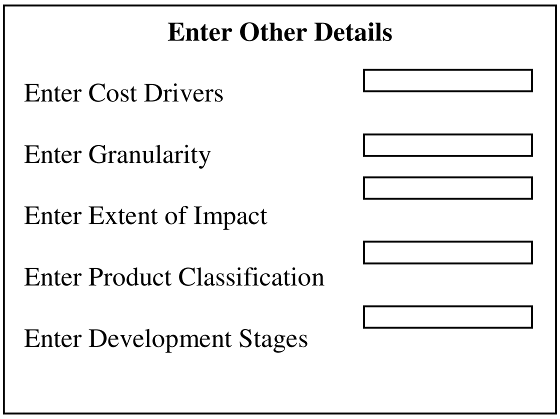
Product
System
SubSystem
FunctionalRequirement
DesignParameter
Constriants
ExtentOfImpact
Granularity
CostDrivers
DevelopmentStages
ProductClassification
Supplier
UserDetails
ListOfFR
ListOfDP
ListOfConstraints
Log

Initial Screen Shots for Back-End Server-Side (design by hand)

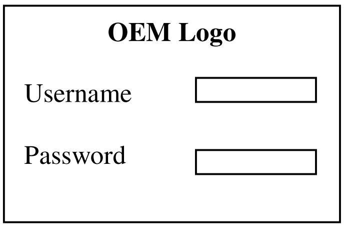


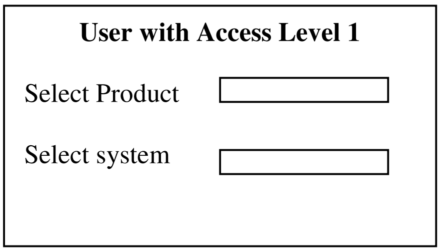


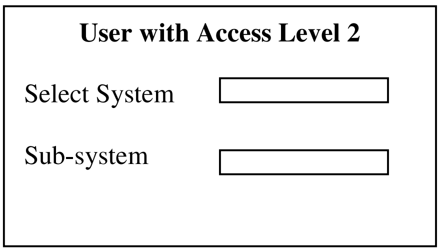


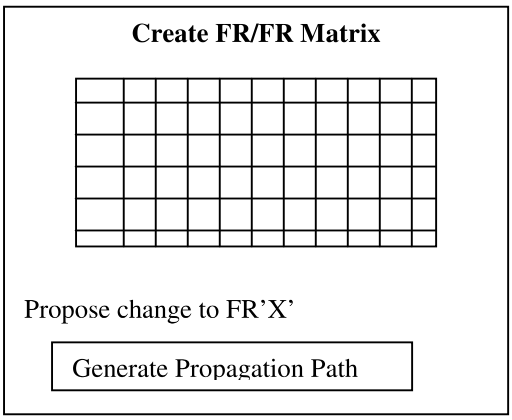


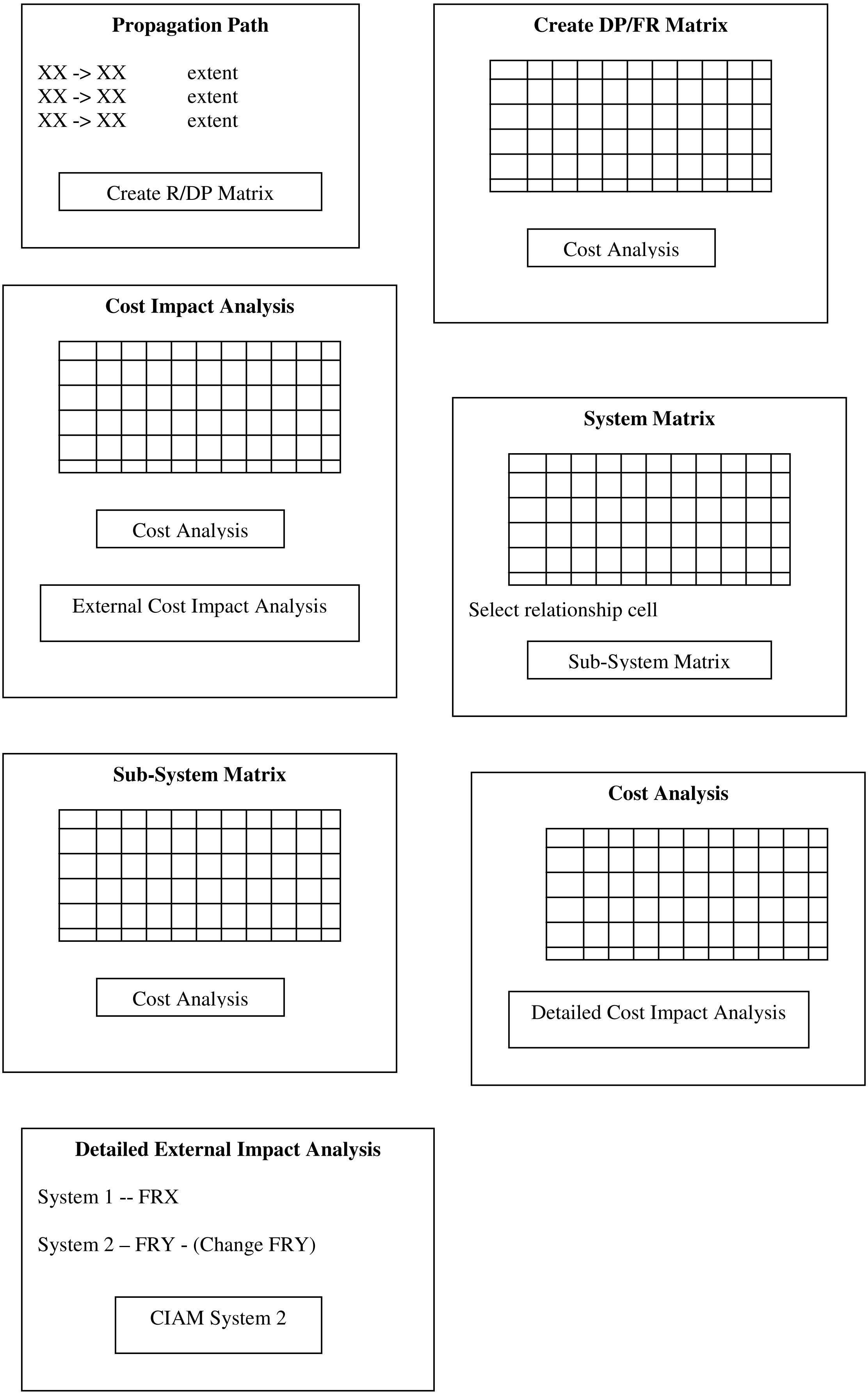
Initial Screen Shots for Front End Client Side (design by hand)





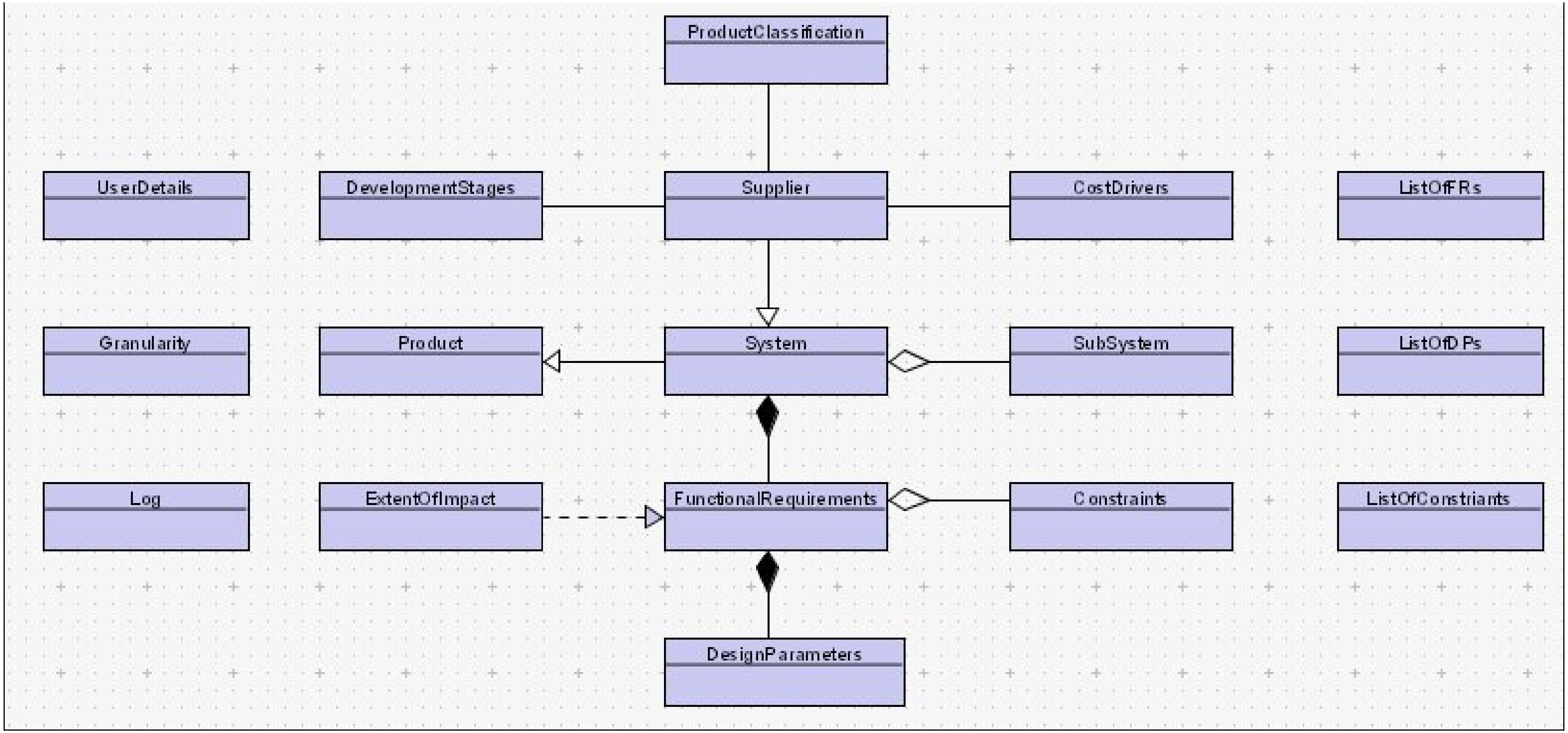




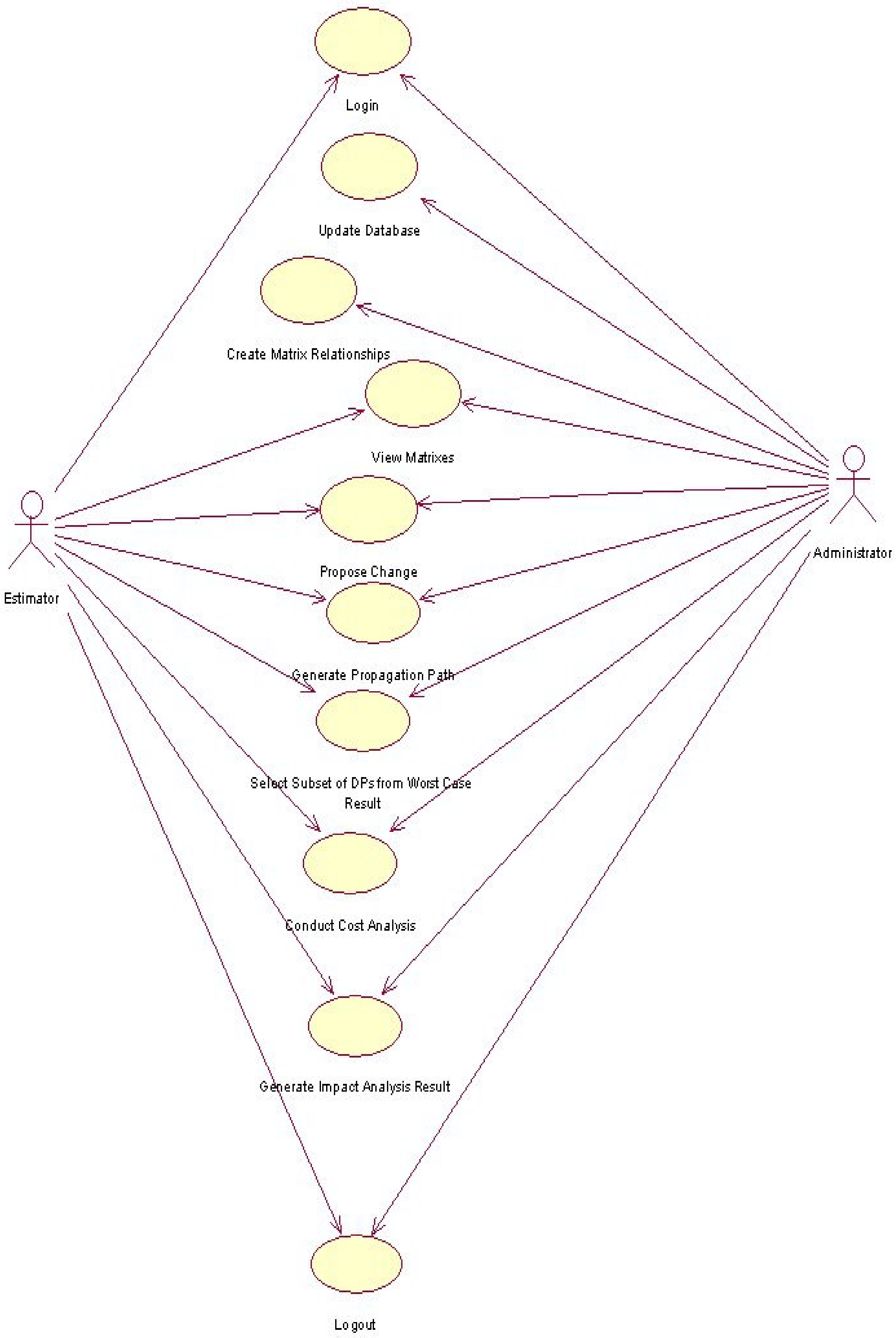

Propagation Path
XX -> XX extent
XX -> XX extent
XX -> XX extent
Create R/DP Matrix
Create DP/FR Matrix
Cost Analysis
Cost Impact Analysis
Cost Analysis
External Cost Impact Analysis
System Matrix
Select relationship cell
Sub-System Matrix
Sub-System Matrix
Cost Analysis
Cost Analysis
Detailed Cost Impact Analysis
Detailed External Impact Analysis
System 1 -- FRX
System 2 – FRY - (Change FRY)
CIAM System 2

Unified Modelling Language (UML)

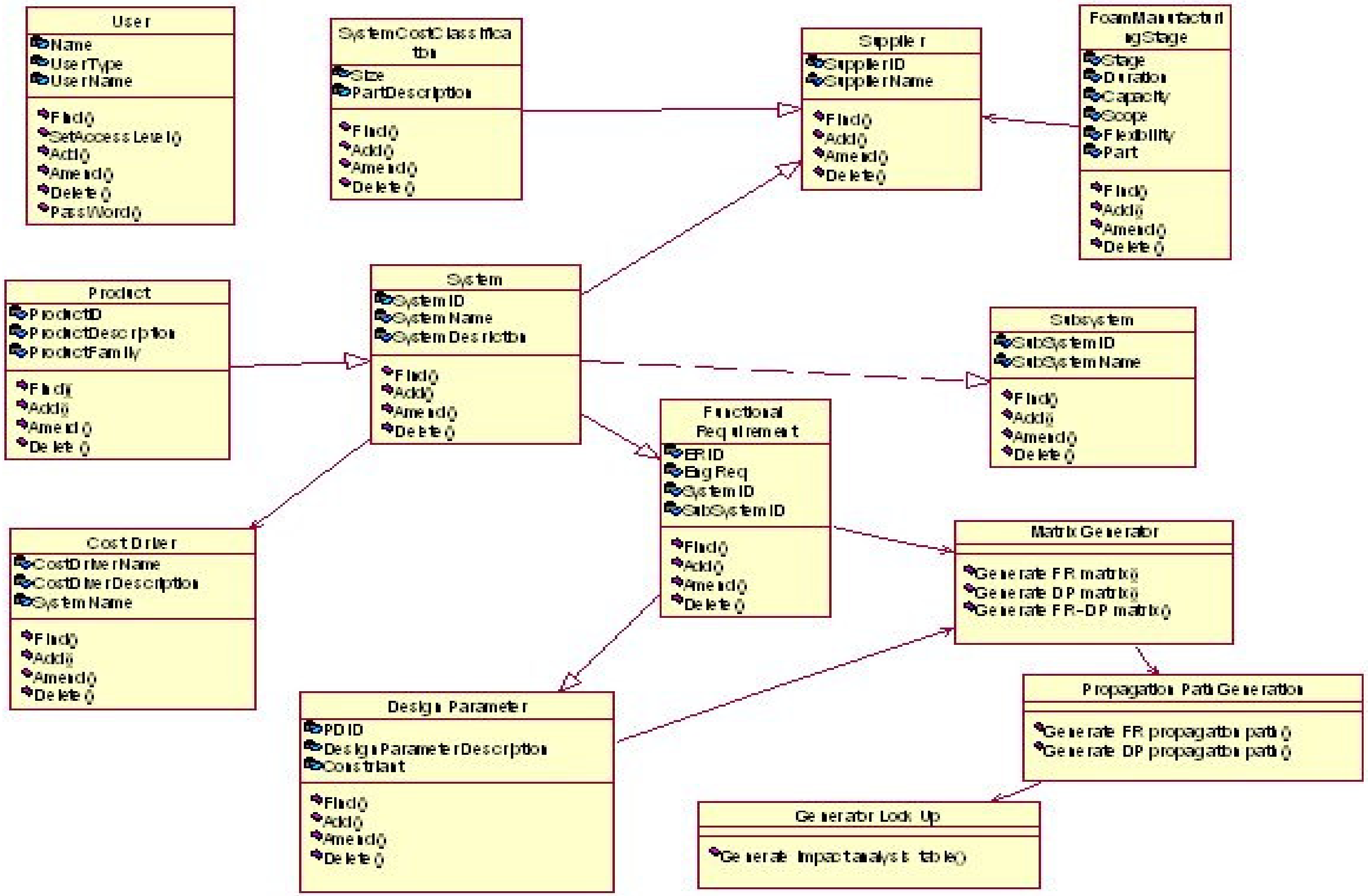
Initial Class Diagram



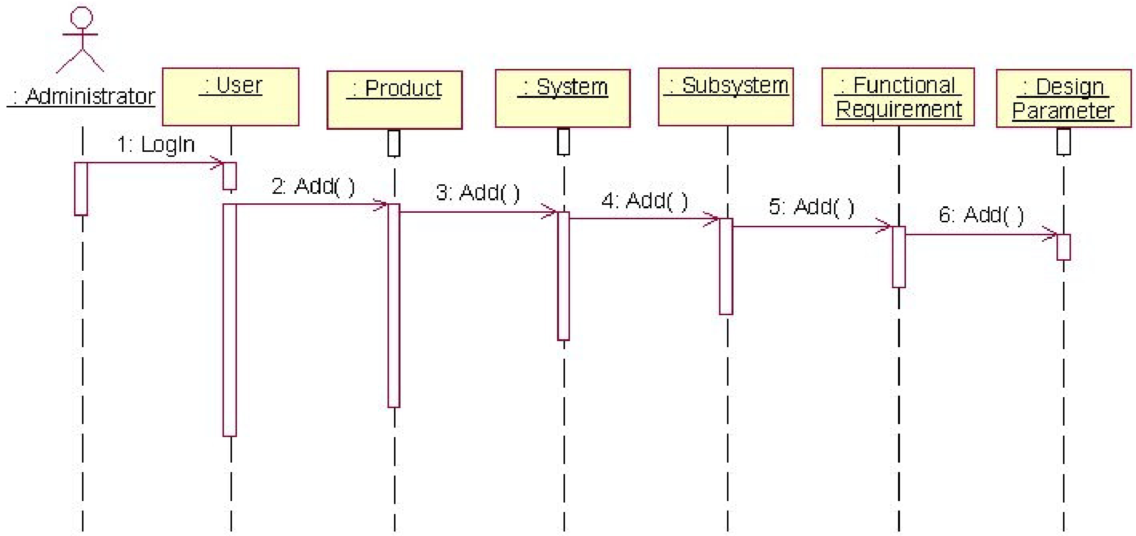
UseCase Diagram

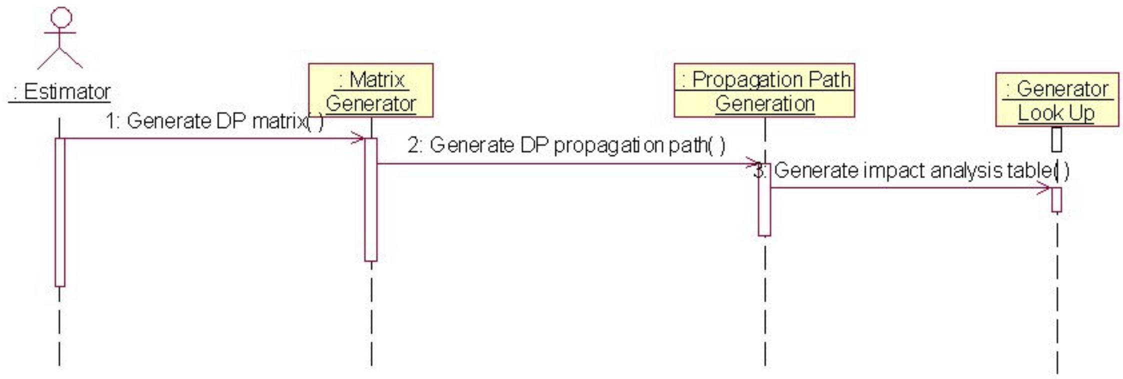


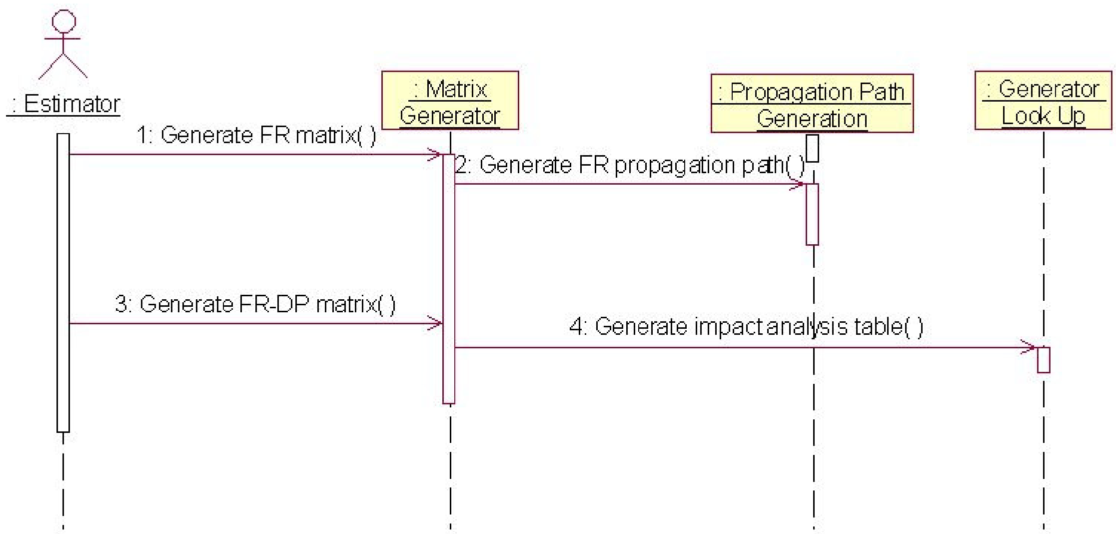
Refined Class Diagram

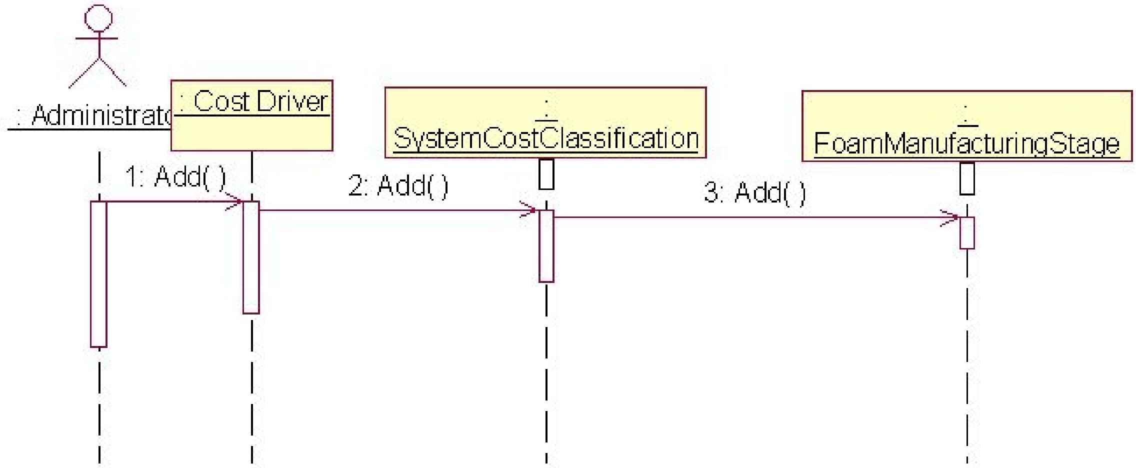


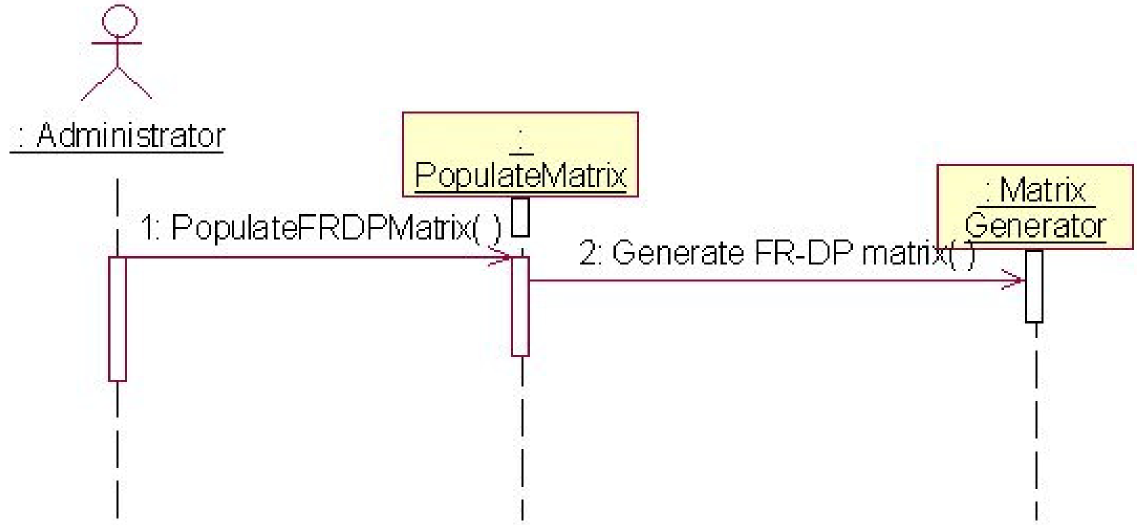
Sequence Diagram



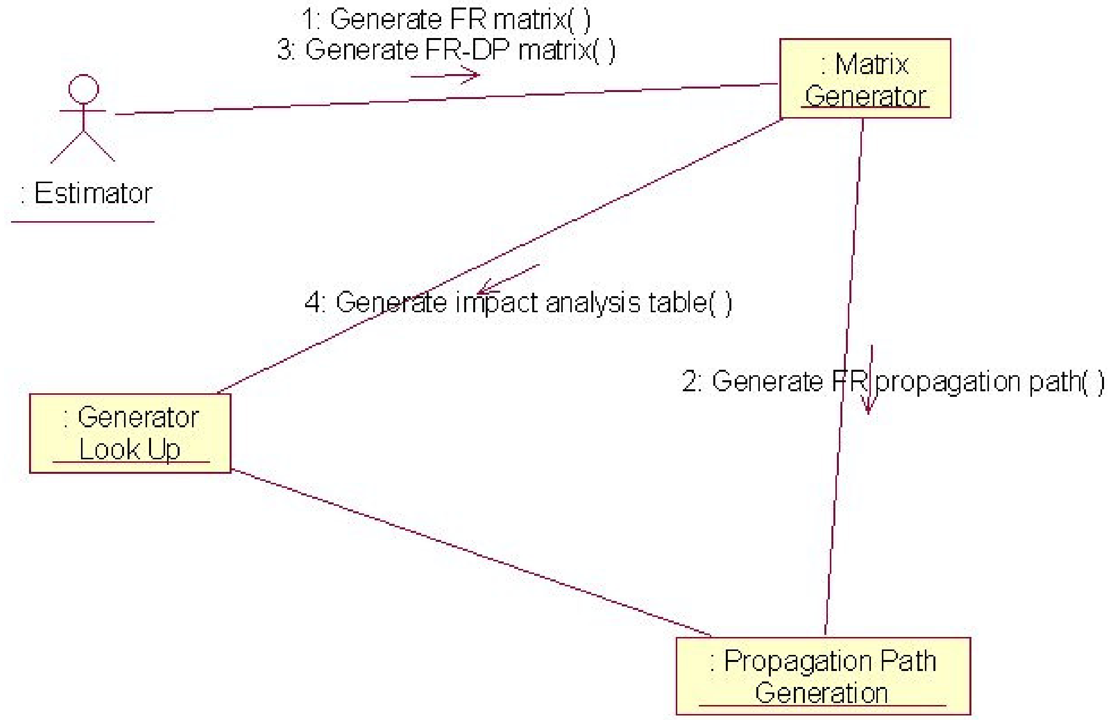


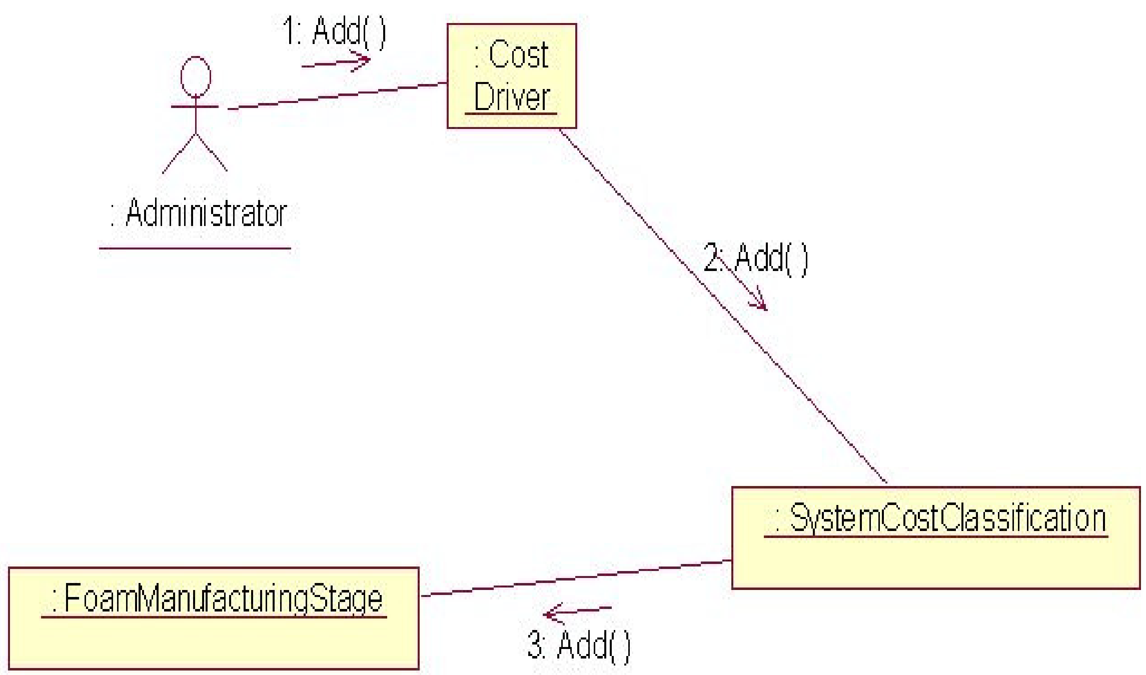


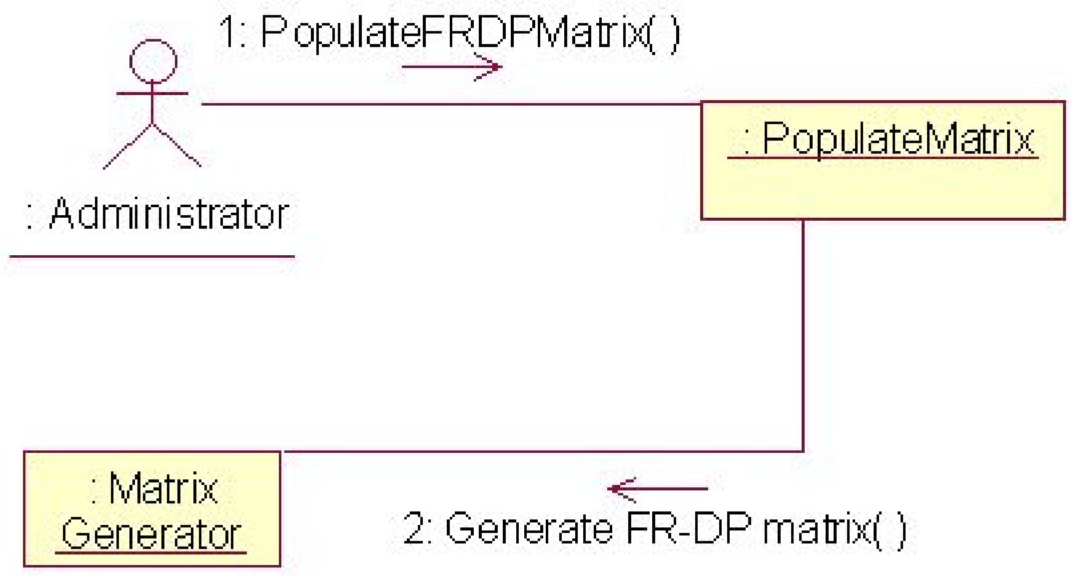

: Administrator
: Cost Driver
: SystemCostClassification
: FoamManufacturingStage
1: Add( )
2: Add( )
3: Add( )

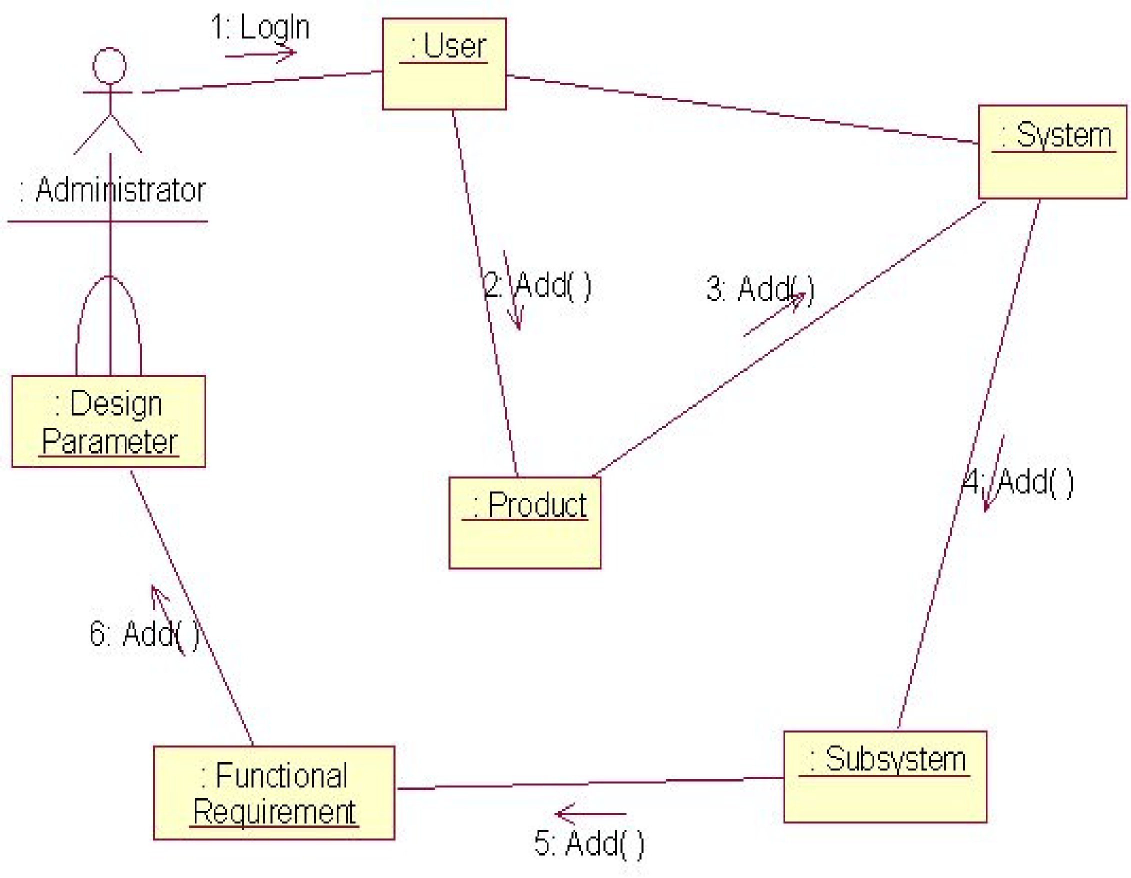

: Administrator
: PopulateMatrix
: Matrix Generator
1: PopulateFRDPMatrix( )
2: Generate FR-DP matrix( )

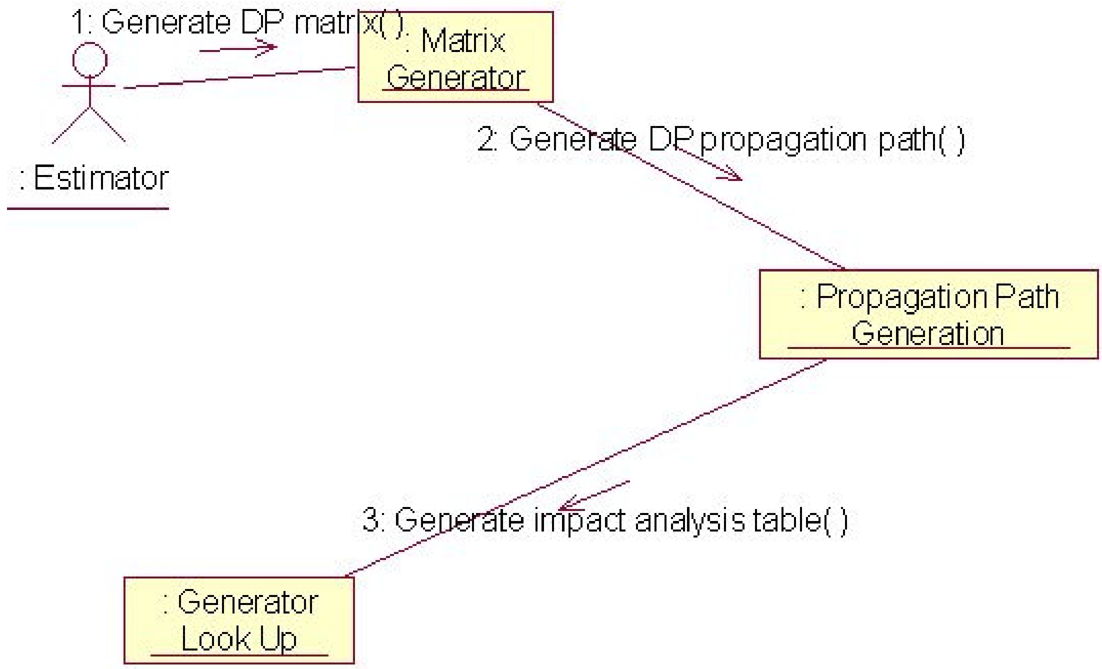
Collaboration Diagram



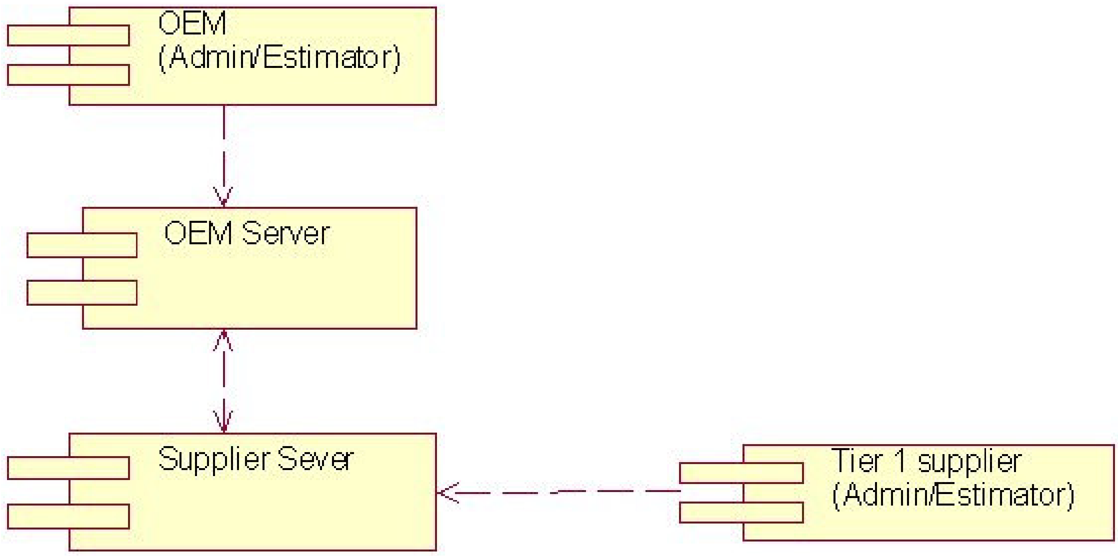



1: PopulateFRDPMatrix( )
: Administrator
: PopulateMatrix
: Matrix Generator
2: Generate FR-DP matrix( )


1: LogIn
: User
: Administrator
: System
2: Add( )
3: Add( )
: Design Parameter
: Product
4: Add( )
6: Add( )
: Functional Requirement
: Subsystem
5: Add( )


1: Generate DP matrix( )
: Matrix Generator
: Estimator
2: Generate DP propagation path( )
: Propagation Path Generation
3: Generate impact analysis table( )
: Generator Look Up

Deployment Diagram



APPENDIX H PROTOTYPE QUESTIONNAIRE

Application of Methodology - Validation

CIAM Purpose

The proposed methodology can be used by OEMs and suppliers for making cost decisions associated with design requirements changes. Within the OEM organisation, the methodology can be used when approving change requests. The methodology will also aid decisions on how feasible a proposed change is. The methodology will reduce rework time since there is visibility of interconnectivity between elements of the product, design engineers will also be able to assess the possibility of subsystem interrelationships before the detailed design phase. Suppliers will benefit from the methodology from various perspectives. Project manager can make economic/profitability decision before committing resources to the implementation of any proposed change. The methodology will provide better understanding of system links at an early stage of the design phase through the complete design cycle.

Aims of Questionnaire

To validate the system from the following perspectives:

- Performance
- Accuracy
- Usability
- Relevance
- Completeness
- Integration into business
- Observations

Benefits to your Organisation

In general the methodology can be used as a cost impact estimation tool for new employees. Both OEM and suppliers will use the methodology for the analysis of change request. The methodology can also be used to define scope of requirement change (propagation path) and cost of change (delta cost). The methodology can also be used to assess work to be done and unveil hidden issues.

NB: Due to anonymity the author will not request for the names of the interviewees. This will also help to reduce bias in the response of interviewees.

Questions

1. Job Title Main role and years of experience

2. Was the above experiences acquired from more than one organization

3. Approximately how many times are you involved in cost assessment of requirement changes (daily, weekly monthly)

4. How would you define cost impact analysis

5. Does the methodology perform cost impact analysis of requirement changes as you would expect.

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

6. Do you agree with the approach to cost impact analysis?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

7. Do you agree with the results of the software?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

8. Is the software easy to use?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

9. Is the software easy to understand?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	**6**
Explain the reason for your choice:					

10. Would you consider the software to be relevant to the automotive organization?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

11. Does the software completely capture all possible scenarios of requirement changes?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

12. Do you think the software can be easily integrated into your current business philosophy, or (any business philosophy)?

Strongly disagree	Disagree	Slightly disagree	Slightly agree	Agree	Strongly agree
1	2	3	4	5	6
Explain the reason for your choice:					

13. What are your general observations relative to the proposed benefits of the software?

14. Other comments

Thank you for your time!