CRANFIELD UNIVERSITY

DOLORS PLANAS

INTELLIGENT E-MENTORING SERVICE FOR COST ESTIMATING

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

MSc THESIS

CRANFIELD UNIVERSITY

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

MSc THESIS

Academic year 2005-2006

DOLORS PLANAS

Intelligent e-Mentoring Service for Cost Estimating

Supervisor: DR J RIOS and PROF R ROY

September 2006

This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science

Abstract

The cost of products and services evolve during a project life cycle. During this time different cost estimates must be made that can be used as fundamental criteria for making design and manufacturing decisions. The competent completion of an estimate requires both knowledge and skills that can be obtained by providing mentoring to the cost estimator.

This study has been undertaken within the Virtual Cost Engineering Studio (V-CES) European project. This project aims to provide two main resources, training for professionals in the area of Cost Engineering in the form of an 'E-mentor' tool and a platform where 'e-training' material can be deployed. The E-mentor is a 'step by step' tool that guides the trainee through the Cost Estimating process based on the three Cost Estimating Methodologies: Analogy, Detailed and Parametric.

In such context, this thesis describes the development of an intelligent e-mentoring tool that provides both support and guidance to the trainee when using the V-CES services. The tool suggests the suitable cost estimating methodology/ies with comprehensive and useful feedback. This thesis also describes the assessment of competences required for the cost estimating process that enables the suggestion of an e-training path and the classification of a cost estimator as a novice or expert. This assessment is based on the knowledge and skills required for each identified competence. The classification of a cost estimator as a novice or expert allows the E-mentor tool to be tailored to the cost estimators needs with feedback given throughout the cost estimating process.

The validation of the developed prototype has been done with cost estimating professionals using both interviews and case studies. The results have proved the developments are useful on enhancing the cost estimator's training.

Acknowledgements

The completion of this thesis would have not been possible without the support of many people and organisations. Firstly, I would like to thank the whole of the V-CES project team: Cranfield members involved in the project, Price Systems, Centre Ricerche FIAT and DAS for the support in terms of resources, expertise, enthusiasm and effort. Special mention should be made to my supervisors Dr. Jose Rios and Prof. Rajkumar Roy for the guidance, inspiration and friendship throughout the duration of the year. Thank you to Jeevan Sagoo for his motivation and support in the many experiences we shared together during the project. A particular acknowledgement is mentioned to Dale Shermon and Shamraz Razzaq for the contribution in the research.

I would like to acknowledge Paul Shields and Alan Lea who participated with enthusiasm and genuine concern to the many validation activities in which they were involved. Thank you to Oliver Houseman for giving advice and a critical view when writing the thesis and to TECOS and Peterborough College for their contribution in the study development.

A big loving thank you to my family: Roser Joan and Raquel, for always being there whenever I needed them. To my friends at home and in Cranfield, thank you so much, your courage and good mood have been outstanding. I give to all of you my sincere and emotional thanks!

Table of contents

Publications

Conference paper

Rios, J., Roy, R., Planas, D., Cochi, F., Shermon, D., Razzaq, S., "A process centred virtual approach to support cost estimating along product life cycle". *12th International Conference on Concurring Enterprising*, Milan, Italy. June 26th – 28th, 2006.

Journal Paper

Rios, J., Planas, D., Roy, R., "Cost Estimating training by doing: a web-based process centred approach". *Intl. Journal of Engineering Education*, accepted 24th Oct, 2006.

List of Abbreviations

AACE	The Association for the Advancement of Cost Engineers
ACostE	Association of Cost Engineers
ASPE	American Society of Professionals Estimators
ATDD	Acquisition Training and Development Directory
CBT	Computer-based training
CBR	Case-based reasoning
CE	Cost Estimating
CEM	Cost Estimating Methodology
CER	Cost Estimating Relationship
CNC	Computer Numeric Control
DoD	Department of Defence
DIF	Difficulty, Importance, Frequency Analysis
FAA	Federal Aviation Administration
GUI	Guidance User Interface
ITS	Intelligent Turing System
JISC	Joint Information Systems Committee
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
KEN	Knowledge = Expert - Novice
K&S	Knowledge and Skills
KSAs	Knowledge, Skills and Attitudes
LOs	Learning Objects
MoD	Ministry of Defence
NASA	National Aeronautics and Space Administration
NCVQ	National Council for Vocational Qualification
NQV	National Vocational Qualification
OGC	Office of Government Commerce
OJT	On-the-job training
OOUI	Object-Oriented User Interface
PBS	Product Breakdown Structure

PFG	Pricing and Forecasting Group
PHP	Hypertext Pre-processor
PI	Programmed Instructions
RA	Real Assistant
RI	Real Instructor
RDBMS	Relation Database Management System
SCAGES	Standing Conference of Associations for Guidance in Educational Settings
SCEA	Society of Cost Estimating and Analysis
SMEs	Small and Medium Enterprises
SOAP	Simple Object Access Protocol
TECOS	Slovenian Tool and Die Development Centre
TEED	Training Enterprise and Education Directorate
TNA	Training Need Analysis
UDACE	National Educational Guidance Initiative
UK	United Kingdom
US	United States
USA	United States of America
VA	Virtual Assistant
V-CES	Virtual Cost Engineering Studio
VLE	Virtual Learning Environment
WBS	Work Breakdown Structure
XML	Extensible Markup Language

List of Figures

List of Tables

1 Introduction

"Assuming that both quality and functionality are satisfied, cost is probably the most influential factor in the outcome of a product or service within many of today's industries".

(Roy et al, 2005b)

The cost of products, projects or services evolves during the project life cycle. Therefore, different cost estimates have to be undertaken due to the different project definitions and data availability.

Cost estimates are important as a decision making criteria, and in that sense they have to be available '*Just-in Time*' when the design solutions are evaluated, and they have to provide a level of accuracy suitable for the stage in which the decisions have to be made *(Roy et al, 2005b)*.

Cost engineers and cost estimators are responsible for creating 'cost estimates', a challenging task because of its complexity; it requires "a lot of experience, data, and knowledge (and skills) of different techniques and methodologies" *(Roy et al, 2005a)*. Knowledge and skills can be achieved through training, leading to gain experience, by using suitable techniques and the appropriate content material.

Training in the cost engineering discipline, and more specifically in cost estimating, is not yet a well established area. Organisations such as Pricing & Forecasting Group (MoD), Department of Defence (DoD), National Aeronautics and Space Administration (NASA) and Society of Cost Estimating and Analysis (SCEA) have developed bodies of knowledge and Certification schemes to identify and integrate training and development programs for the cost engineers.

Universities, such as *West Virgina University* and *Iowa State University* are providing training courses in cost related disciplines. They run from one day to twelve months (average of two days duration). Some provide online facilities like the delivery of training material and mailing contact, and some include content in the various Cost Estimating Methodologies (CEMs).

Virtual Cost Estimating Studio (V-CES) offers the users of the service more choices other than training courses. It aims to provide e-mentoring in cost engineering. The concept of mentoring is defined as "*a dyadic relationship in which a mentor, a senior person in age or experience, provides* ***guidance*** *and* ***support*** *to the less experienced person, the trainee*" (V-CES Consortium D2.4, 2005). Guidance and support to the cost estimator is provided by defining an online platform with different integrated services. The electronic (or automatic) guidance and support is named e-mentoring and the physical people defining the e-training courses or involved in the e-community providing expertise, mentors.

The services mainly cover the delivery of online courses, the community contact between mentors and trainees, providence of others resources such as a glossary of terms, and a 'step by step' tool (E-mentor) to help the creation of cost estimates based on the Cost Estimating (CE) process. This tool provides the first layer of e-mentoring as it guides the cost estimator using a 'Best Practice' CE process. None of the training programs identified in literature includes e-mentoring features with a similar 'step by step' tool.

Within this platform more guidance and support can be provided. This study aims to help the cost estimator improving his/her performance when developing cost estimates. This has been performed by bringing intelligent e-mentoring features to the system. The name intelligent refers to the ability to identify characteristics or patterns in the cost estimator, the project to estimate and to provide guidance and support.

1.1 Cost Estimating

The cost engineering and cost estimating areas are receiving more and more interest within companies. The relevance of cost, the need to understand it and predict it applying engineering principles, has been widely recognised by the industry.

"*Cost engineering is concerned with cost estimation, cost control, business planning, management science, including problems of project management, planning, scheduling, profitability analysis of engineering projects and processes*" (Roy, 2003).

This research focuses on the cost estimation area defined by SCEA as: "*The art of approximating the probable cost or value of something based on information available at that time*". Cost estimating is an essential activity for many successful companies. It is the starting point for discussions on the viability of new projects. Cost estimates assist decision-making, budgeting, tenders, cost reduction, feasibility studies, and setting prices (Rush et al, 2003).

The CE process (and the three CEMs: analogy, detailed and parametric) has been the key driver of the research.

1.2 Research Context: Virtual Cost Estimating Studio (V-CES)

The Virtual Cost Engineering Studio (V-CES) is a European project which has been developed within the Decision Engineering Centre at Cranfield University which the author has been involved with. This is the context of the research that this thesis describes.

The aim of the V-CES project is to develop a virtual infrastructure to train cost estimating professionals and to allow companies to share cost engineering practices. The training is seen as “the process of gaining knowledge and the skills needed for developing cost estimates” (Roy et al, 2005).

The motivation for the V-CES project has arisen from the following major market findings (Roy et al, 2005):

- Lack of training in cost engineering and cost estimating, especially based on the CE process and its CEMs.
- Cost estimating software is mainly developed to calculate cost estimates for a variety of products, but without providing a ‘step by step’ guidance in how to develop the cost functions.
- There is a need to have a transparent description of the cost structure, showing the origin of the cost drivers and to have a better visibility of the basis upon which *ad hoc* decision is based.
- The e-Learning market is growing globally, in particular the European business skills market has an estimated value of 15 billion Euros by 2006, and it is estimated that around 30% of this market will be delivered via e-Learning. This is providing the benefit of training ‘available at any time and anywhere an Internet connection exits’ and easy access as it does not require any software installation.
- A potential market for SMEs has been identified to use the service.

1.2.1 Potential Users of V-CES

V-CES aims to develop and deploy a set of virtual services to the cost engineering community approaching manufacturing practices. This implies the possibility for the cost professionals of exercising a just-in-time training, estimating and consulting directly to their work (V-CES Consortium D1.5, 2005).

A particular profile to be especially addressed is the ‘SME’, as being recognised by the European Commission that they need to increase and improve their technological level, organisational and training practices (V-CES Consortium D1.5, 2005).

From a survey, V-CES identified the generic profile of the professional willing to use the service as a potential user (V-CES Consortium D1.5, 2005):

- They range from medium level of vocational training to a professional with a university degree.
- Most of the participants came from a manufacturing background, design and management.
- There is a limited awareness of different cost estimating techniques apart from the ones used in their daily work.
- In addition to pure cost estimates creation, other activities in the cost engineering discipline are performed by the participants such as: Risk Analysis, Value Analysis, Cost Modelling, and Design to Cost.
- Many of the professionals do not have a clear picture of the benefits of sharing practices within and outside the company. However, professionals from OEMs involved in the evaluation of bids are the ones with a clearer picture of the benefits.
- Most of them have a user level in IT.

The potential users are individuals or organisations who recognise the possibility to better understand their cost breakdown structures, identify the sources of risks and contingencies, use the estimates as a best practice to show transparency and build trust with the shareholders (especially with suppliers), establish networking within the cost engineering community and develop their knowledge and skills within cost engineering; provided by V-CES services.

1.2.2 Description of the Service and Technical Architecture

The three main services provided by V-CES are: V-CES mentor, V-CES training and V-CES community (see Figure 1-1).

<u>V-CES e-mentor</u>

The current V-CES E-mentor defines and implements the CE process using the three different CEMs: detailed (or bottom-up), analogy and parametric as a set

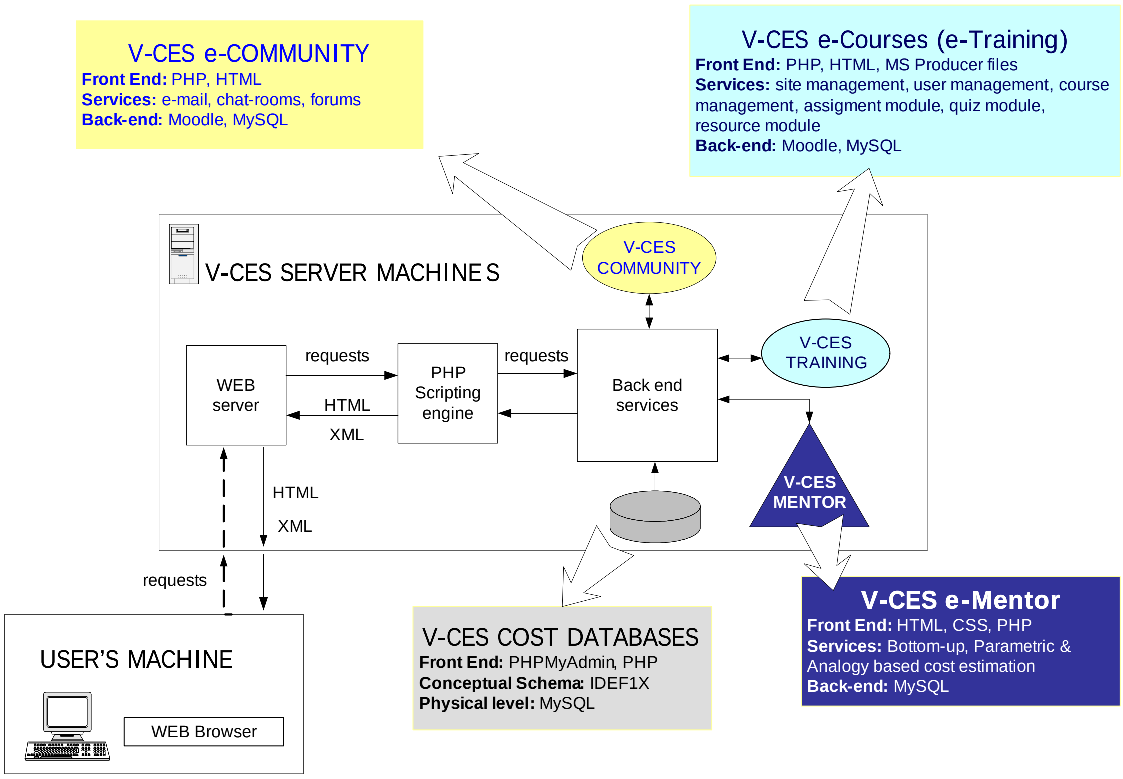
of steps where the user has to input parameters. The different activities are shown and detailed in section 2.2.
The learning process is addressed by '*e-training by doing'* (V-CES Consortium D2.4, 2005).

V-CES e-training
The V-CES e-training, supported by the Moodle application, organises the e-training material according to general topics such as: e-courses or glossary of terms. Moodle is a free open source content management system (CMS) to help educators create online courses (Moodle, 2005).
The learning process is addressed by '*e-training by lecturing'* (V-CES Consortium D2.4, 2005).

V-CES e-community
The V-CES e-community is a platform supported by Moodle to establish a direct contact between trainees and mentors through mailing and chatting online. This has not been addressed by this study.
The learning process is addressed by '*e-training by discussions'* (V-CES Consortium D2.4, 2005).

V-CES Cost Databases have been defined as a supporting means for the estimating activities in cost engineering.

Figure 1-1 depicts the network framework in which the outcomes have been deployed, which demands a hybrid client-server and peer-to-peer interactions. A group of network technologies need to be considered: Simple Object Access Protocol (SOAP), Extensible Markup Language (XML) Technologies, HyperText Markup Language (HTML), Hypertext Pre-processor (PHP), Web protocols, Virtual Learning Environments, and development frameworks like the Java based J2EE and multi-agent systems middleware like JADE. The access to such services is completed via Internet and a Web browser (Roy et al, 2005).



Source: (V-CES Consortium D2.4, 2005)

Figure 1-1: The V-CES services technical solution

1.3 Problem Definition

The previous research context is setting up a platform to train cost engineers and cost estimators, particularly in the area of cost estimating. Main resources available are reviewed as the following:

- E-mentor as a CE process.
- E-training courses.
- Glossary of terms and links to organisations.
- E-community.

E-mentoring, understood as guidance and support to the cost estimator, is contained in the design of the E-mentor tool itself. This guides the cost estimator through different screens which are the steps required to carry out a cost estimate. More guidance and support can be provided to the cost estimator within the platform of services implemented by V-CES. Intelligence can be brought to the system in both the use of the E-mentor tool and the training process for the cost estimator.

1.4 Research Aim

In view of the research context and the problem area outlined the aim of the research is to:

"Develop an intelligent e-mentoring service on product cost estimation, focused on manufacturing. This e-mentor has to facilitate the learning process of the trainee needs, based on his/her competences and on the cost estimating process to be used".

1.5 Research Collaboration

The development of this research has been carried out within the V-CES project. In order to define and validate the research areas, various professionals have been approached, especially from the Automotive, Aerospace and Semi-Conductor Equipment Treatment industrial sectors.

The nature of the research involves both the Cost estimating discipline and Training, therefore professionals related with two areas have been considered. The research has been carried out with professionals from the following organisations and academic establishments:

- Price Systems (UK, industrial partner of V-CES)
- Centre Ricerche FIAT (Italy, industrial partner of V-CES)
- DAS (Germany, industrial partner of V-CES)
- Cranfield University (UK)

- TECOS (Slovenia)
- Peterborough University (UK)
- Ministry of Defence (MoD, UK)
- External Consultants

1.6 Thesis Structure

The introduction (chapter 1) provides a top level overview of Cost Estimating, Training and Development. The context of the research (area, project and collaboration) is presented.
Chapter 2, ‘Literature Review’, reviews the related literature to understand the concepts involved in the research such as CE process, training and intelligence. It also identifies: what has been done within the research aim area (offer guidance in the cost estimator training), the information to use when developing the research solutions and the limitations observed.

Chapter 3, ‘Research Aim, Objectives and Methodology’, details the strategy after the literature survey in order to define the aim and objectives. The methodology deployed ensures that the research has been carried out in a structured way which can be followed and validated.

Chapter 4, ‘An Intelligent e-Mentoring Service Framework’, defines and presents the framework for each of the areas where intelligence has been incorporated. It is based on inputs from the literature review, understanding of the research context and validation from cost estimators. Validation in this chapter has been accomplished independently for each of the areas where intelligence has been incorporated.

Chapter 5, ‘Implementation of the Framework’, shows the way the framework has been implemented in a web-based environment. The developments achieved within the research context project have influenced this research implementation. Individual validation of the area of ‘suggesting the Cost Estimating Methodology’ has been carried out at this stage.

Chapter 6, ‘Definition of Test Scenario and Prototype Validation’, covers the test scenario to validate the approach within the cost estimating discipline. The validation of the prototype at the implementation stage through two case studies is intended to test the whole prototype in a situation which is close to real practice.

Chapter 7, ‘Discussion, Future Research and Conclusion’, summarizes the main findings from the research and these are presented and discussed. The conclusions cover the achievement of the objectives and the answer of the research questions. The chapter closes with research limitations and future possibilities.

The following chapter in this thesis provides details of the literature review. This includes the areas of; training, the CE process, the cost estimators’ knowledge and skills and intelligence web-based applications for training purposes.

2 Literature Review

The literature review examines the published literature that leads to understand how cost estimators can be helped when carrying out cost estimations.

2.1 Overview

Section 1 evaluates how this help implies a process of learning, training and mentoring (Figure 2-1). A Training Needs Analysis (TNA) shows if there is any need (when understanding and carrying out the CE process) that could be improved by training. Training techniques are also observed. The literature reviewed also covers the characteristics of the electronic environment and focuses on identifying the existing online training material in cost estimating.

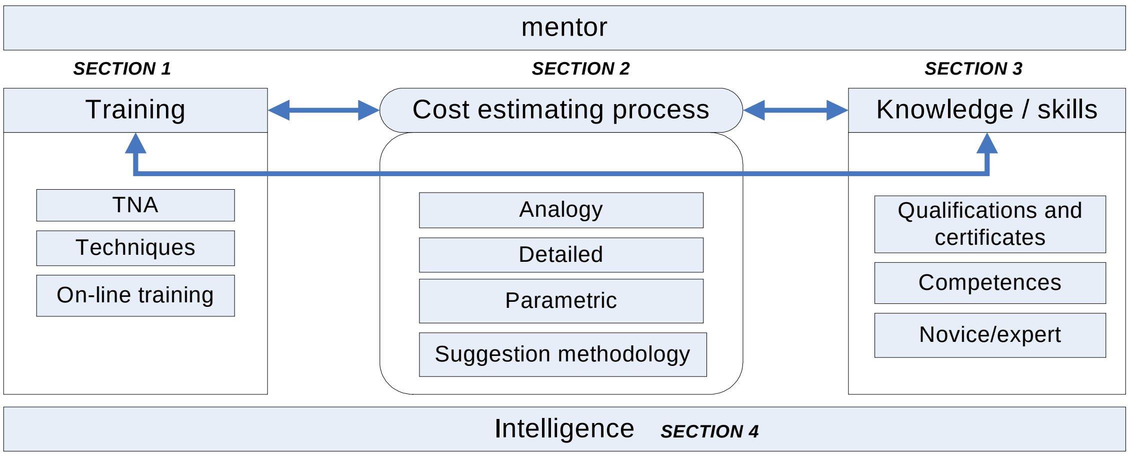


Figure 2-1 Topics in which literature review has been carried out

Section 2 focuses on analysing the process required to create cost estimates (Figure 2-1). After a general overview of cost estimating, the literature review proceeds to the CE process and the three CEMs targeted: analogy, detailed and parametric (focusing on the V-CES framework). Special part of the mentoring is deployed on the suggestion of the Cost Estimating Methodology (CEM). Therefore, there is a detailed analysis about the criteria for the selection.

An important part of the mentoring is the suggestion of the training material. This suggestion depends on the knowledge and skills required to understand the CE process. Different approaches such as qualifications, certifications and competences consider the acquisition of knowledge and skills. This literature is also reviewed (Figure 2-1, section 3). The definition of knowledge and skills is leading to the identification of the cost estimator as a novice or expert.

The e-mentor is intelligent, this means it suggests decisions based on inputs in the following items:

- The selection of the CEM.
- The suggestion of e-training material according to competences.
- Recognition of the cost estimator as a novice or expert.
- The feedback during the CE process.

Finally the literature reviewed examines the current trends in intelligent web-based training (section 4, Figure 2-1).

2.2 Learning, Training and Mentoring

Definitions of *learning* found in literature vary according to the theoretical background of the authors. Blanchard and Tracker (2004) refer to the term *learning* as a relatively permanent change in cognition (i.e. understanding and thinking) that results from experience and that directly influences behaviour. Talbot (2003) states learning is essentially the acquisition of new skills, knowledge and attitudes, and the recognition of how they relate to the skills, knowledge and attitudes you already possess. Learning is also the process of understanding what has been acquired, and applying it to both familiar and new situations.

The ‘measure of learning’ is a very tricky issue because it demands the understanding of ‘how the learning process occurs. It is necessary to observe something influenced by learning. Blanchard and Tracker (2004) explain main pedagogical approaches for the learning process:

- Behaviourist: it is based on observing the learner's behaviour (e.g. answers, performances, etc.).
- Cognitive: it is based on the change in the content, organisation, and storage of information. The term refers to the mental processing of information.

Bloom et al. (1956) classified the outcomes of learning into three domains:

- Psychomotor: to do with the skills.
- Cognitive: to do with thinking abilities: comprehending / understanding information, that is, what we know and what we do with what we know.
- Affective: to do with attitudes and approaches.

Although these categories and levels were defined some 50 years ago, they are still regarded relevant and used by many researchers.

Blanchard and Tracker (2004) define *training* as a systematic process of providing an opportunity to learn Knowledge, Skills and Attitudes (KSAs) for current or future jobs (see his KSAs definitions in section 2.3.2.1).

In the V-CES project (V-CES Consortium D2.4, 2005) these terms are defined as:

- *Learning*: "the process of gaining knowledge through studying";
  knowledge being "the information and understanding about a subject that a person has".
- *Training*:" the process of learning the skills for a <u>particular</u> job or activity";
  skill being "the knowledge and ability that enables a person to carry out an activity properly".

According to the concept of mentoring defined in chapter 1, the mentor may have three functions: vocational (or instrumental) support, psychosocial support, and as a role model.

The profile of the mentor depends on the kind of discipline to be trained or learned. According to Woolf et al. (2001), engineering tutors coached rather than taught and required less knowledge about correct answers and more information about the domain.

In this thesis, the electronic/automatic (not human) guidance and support is named e-mentoring and the physical people defining the e-training courses or involved in the e-community providing expertise, mentors.

2.2.1 Training Needs Analysis

The training needs of employees have recently been receiving more interest by companies as this improves the knowledge and skills of the employees to complete the tasks more effectively. But its effectiveness strongly depends on the suitability of the training material and the employee needs. The difficult part is to establish the areas of expertise and by which methods to train the employees.

The definition of any training package, what could be considered as a product/service, demands the application of a basic principle: ‘needs analysis’. The first issue to address is if there is any need that could be improved by undertaking training (V-CES Consortium D1.5, 2005). Blanchard and Tracker (2004) state that a “TNA is important because it helps to determine whether a deficiency can be corrected though training”. Roy et al. (2005b) identified the need for training, stating that cost engineering and management has been identified as one of the most important topics by companies. The need for education/training in this area in order to achieve business competence has been mentioned.

Many authors see TNA as a process. Blanchard and Tracker (2004) justify it by quoting: “Training Needs Analysis (TNA) is a systematic method for determining what caused performance to be less than expected or required”. The focus of training is performance improvement. A TNA can be proactive and reactive. A proactive TNA focuses on an anticipated performance problem in the future. A reactive TNA focuses on a perceived lack of performance in the past and present. It implies an organizational analysis (objectives, resources, environment), an operational analysis (expected performance for a job), and a person analysis (current performance on that job).

Mishra et al. (2002) show the system approach to training in Figure 2-2, which considers the TNA as the first step. They add that without a systematic approach to TNA, training could be provided that is not required, that does not transfer to the work environment, that is too early or late to be useful and that is 'training for training's sake'.

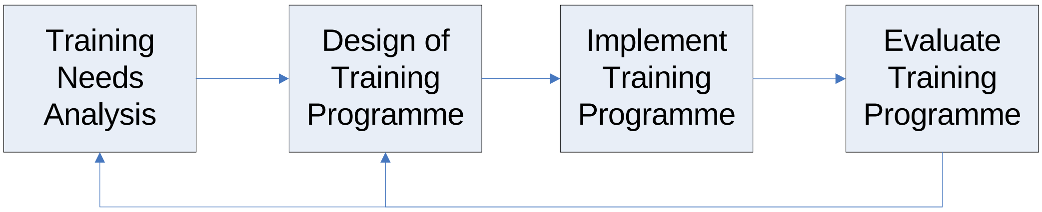


Figure 2-2 System approach to training (TNA)

Grant (2004) mentions that any training has to take into account the complexity of the tasks. These tasks may be broken down in to easier tasks, but the depth of the analysis depends on time and resources.

Difficulty, Importance, Frequency Analysis (DIF) is a term for techniques that attempt to rate which aspects of the task should be included in a formalised training programme and others not to be included (Table 2-1). Mishra et al. (2002) firstly applied DIF techniques within the costing profession to assess training needs. It was used to determine the relevant training requirement associated with each of the knowledge categories. Other authors have also used it, for instance Grant (2004) used it as a basis to score skills and knowledge against standards.

Table 2-1 DIF analysis definition from Mishra et al. (2002)

D	Difficulty	Difficulty in learning / performing
I	Importance	Level of criticality of task to job performance; or consequences of error.
F	Frequency	How often task has to performed

A training needs analysis has been undertaken within the research context project (V-CES) and should be also completed when defining the e-courses content.

2.2.2 Training Methods

Different authors have pointed out the differentiation of training knowledge and skills. Pascail (2006) highlights the idea that “higher education no longer simply seeks to transmit knowledge but also to train students in skills”. It mentions the powerfulness of understanding the theories and linking them to practice. These theories are what current thesis approaches with knowledge and practice with skills. Michau et al. (2001) mention that the evolution of learning and teaching must be oriented toward the skills required of engineers.

Mishra et al. (2002) differentiate between passive and active learning. Passive learning is associated with a more traditional approach, where a student receives information from an instructor/tutor. Active learning generally ensures more productive results. Examples of active learning are: On the job training; Mentoring, shadowing (‘Sitting with Nellie’, SWN) and job rotation, off-the-job training, workshops, case studies, role playing, simulations, problem solving, interactive computer learning packages and CBT.

V-CES project refers to the terms ‘training by lecturing’ and ‘training by doing’ as different main approaches to provide learning and training (V-CES Consortium D2.4, 2005).

Blanchard and Tracker (2004) describe various training techniques, defining the formats, purposes, strengths, and limitations. The methods are:

- Lectures, discussions and demonstrations.
- Computer-based training (CBT).
- Games and simulations.
- On-the-job training (OJT).

The relevance of the training techniques identification is to evaluate the most suitable learning objectives per method. Blanchard and Tracker (2004) focus on which methods target knowledge, skills and/or attitudes (KSAs). This work is interesting because of the differentiation of knowledge and skills and its relation with useful training material. This has been one of the main drivers of this study. The limitation is that some of the methods are deployed in a face-to-face environment, so they have needed to be adapted to become resources in the web-based framework as defined in the V-CES project.

2.2.3 Web Based Environment and E-training

The term e-training is not widely used, and its difference with e-learning should come from the difference between 'learning' and 'training', and not from the technology used in its deployment. E-training is then defined as: "training facilitated and supported through the use of information and communication technology" (V-CES Consortium D1.5, 2005).
The implementation of e-training is an area of research and development that is receiving more attention. This is mainly due to the impact of the computed-mediated-communication aspect and its clear benefits (V-CES Consortium D2.4, 2005).

The electronic environment enables (Ensher et al, 2003; Boyle and Muller, 1999):

1- To receive an available 'Just in Time' training, at any time and anywhere if an Internet connection exists. The importance of this idea relays in the fact that relevant part of the information learnt on a training course is forgotten by the time the trainee needs it.

2- To minimize personal constraints for minority masses regarding male/female sex or cultural biases.

3- To have richest access to the variability and availability of mentors.

Main limitations are seen from a social point of view, such as confidentiality issues (training path), assessment difficulties, need to strong self-discipline and lack of human contact (Ensher et al, 2003; Boyle and Muller, 1999; Michau et al, 2001).

E-learning has been identified to be in phase with current industrial trends for its flexibility and multiform. It allows greater personal involvement in organizing and choosing courses (Michau et al, 2001; V-CES Consortium D1.5, 2005). V-CES Consortium D1.5 (2005) mentions the importance to bear in mind the ‘individual learning’, because it seems that some employees get enrolled in e-learning programmes independently from their company training activities. It also studied the relationship and relevance of e-learning to Small and Medium Enterprises (SMEs). The report pointed out the following concerns:

- Many SMEs lack a basic learning culture or organised training plans and infrastructure.
- There is little support from managers for introducing e-learning.
- There is no organised and planned action to take up e-learning.
- Access to broad bandwidth seems to be a problem.

2.2.4 Virtual Learning Environment (VLE)

According to Joint Information Systems Committee (JISC, 2006), e-learning can be defined as “*learning facilitated and supported through the use of information and communication technology*”.

Quoting JISC information,

“E-learning may involve the use of some, or all, of the following technologies”, known as well as computer assisted cooperative work:

- Desktop and laptop computers.
- Software, including assistive software.
- Interactive whiteboards.
- Digital cameras.
- Mobile and wireless tools, including mobile phones.
- Electronic communication tools, including email.
- Discussion boards, chatting facilities and video conferencing.
- Virtual Learning Environments (VLEs).
- Learning activity management systems.

In order to implement JITT in cost engineering, V-CES considers that the trainee is using computers and a Web browser to access the service, where courses and training material are available on-line through a VLE.

Typically, a VLE may integrate all or part of the following tools and services (European Schoolnet, 2003):

- Both synchronous and asynchronous tools for communication and collaboration
- Access to repositories of Learning Objects (LOs)
- Templates and authoring tools to create, edit and re-use LOs and other types of content
- Automatic generation of metadata for learning resources
- Tools to sequence LOs to create modules and courses
- Tracking of students progress through content
- Assessment tools for learning progress
- Access to online help and tutoring
- Linking students data and administrative information
- Diagnostic tools to provide some kind of ‘intelligent tutoring’ for personalized re-sequencing of content and assessment

Michau et al. (2001) offer a web-application on Control Engineering for both academia and industry. It uses a tool called Lotus Learning Space which can be considered as a VLE. It provides a space to organise the modules, exercises and simulations with deadlines if desired. Moreover, it is a virtual space to communicate and store the profiles of the people involved. The graphical interface provides different exercises using *Matlab* web thus allowing simulations to be viewed and self-training to be undertaken. The limitation of this work for current research is that it does not target cost engineering, but it proves that the use of a VLE offers flexibility to individuals and companies when tailoring the courses, infrastructure organisation for planning and the merging (concentration) of material from different sources.

This study makes use of the service provided by V-CES through the Moodle platform as VLE to fulfil the requirement to provide services related with training material from a unique platform. Other VLEs have not been analysed. The idea is to incorporate features to fulfil new requirements and to integrate them with existing resources to present a uniformed solution (centralisation of resources).

2.2.5 Online Training in Cost Estimating

Roy et al. (2005b) mention a lack of availability of online training material in cost engineering. Their literature review found training material from the following sources:

- The Association for the Advancement of Cost Engineers (AACE) International (www.aaei.org)
- Al Dell'Isola (www.vecourse.com)
- West Virgina University (www.elearn.wvu.edu)
- COSTProf: CD-ROM from SCEA.
- The American Society of Professional Estimators (http://www.aspeeducation.org/)
- Company MindLeaders provides online training course on "Project Management: estimating and scheduling resources" (2 hours)

Other training programs targeting the cost estimating discipline have been found in the literature reviewed by this study. They have been analysed and discussed by looking at the following parameters:

- Duration: to give an idea of the deepness of the course.
- Characteristics: to mention any relevant feature (such as certification).
- Online: to point out if the course is available online or not.
- CE process: to see how well they target the focus on the CE process based on the 3 CEMs: analogy, detailed and parametric.

Sources identified that provide training in cost estimating are:

- “Fundamental Skills and Knowledge of Cost Engineering”.
  Iowa State University
    - Duration: Maximum of 12 months for course completion.
    - Characteristics:
      - 7.5 Continuing Education Units (CEUs) and a certificate of completion issued by Iowa State University.
      - Preparation for the certificate exam done by AACE.
    - Online: Post transference of training material/assignments. Possibility to get feedback and questions by mail.
    - Focus on the CE process based on the 3 methodologies: Partial.
- “Acquisition Training and Development Directory (ATDD)”
- *Ministry of Defence (MoD)*
    - Duration: Not Applicable as there are different courses.
    - Characteristics:
      Formal training, reading, distance/interactive, e-learning and work experience is provided
    - Online: partial.
    - Focus on the CE process based on the 3 methodologies: Partial.
- “Project Management: Estimating Costs”. *Serebra (Canada).*
    - Duration: 4 hours.
    - Online: yes.
    - Focus on the CE process based on the 3 methodologies: No.
- “MDO270 – Online Project Cost Management”. *Boston University.*
    - Duration: Not specified
    - Characteristics:
      - Outcome: part of the Project Management Certificate.
      - Attendants: designed for project managers but not for professional full-time cost estimators.
    - Online: Yes.
    - Focus on the CE process based on the 3 methodologies: Yes.

- "Project Cost Estimating and Budgeting (PMBOK 2000)". *Australian Institute of Project Certification Program SkillSof.*
    - Duration: Not specified
    - Online: Yes.
    - Focus on the CE process based on the 3 methodologies: Yes.
- "Cost Estimating and Budget Analysis Practices" and "Foundations of Cost Estimating". *University of Halabama in Hunstville* (*http://www.coned.uah.edu/sessioninfo.cfm?courseid=FCES*)
    - Duration: 12-18 hours
    - Online: Yes
    - Focus on the CE process based on the 3 methodologies: No.

Two other non online courses (offline) have been identified (2 days duration):

- "Project Cost Estimating". *California Institute of Technology/Caltech*
- "Cost Estimating" (based on the book *Cost Estimating* by Rodney D. Stewart). *ESI International (Washington or Las Vegas);* it also offer courses than can be done e-learning.

When looking at the cost engineering (and cost estimating) training courses content, most of them are related to general concepts in cost engineering and cost management, but they do not particularly target the training on the CE process and the CEMs.

2.2.6 Key Observations and Limitations

The literature review has identified following key observations and limitations:

- Roy et al. (2005b) and the author literature review have identified a lack of availability of online material in cost estimating, especially focusing on training in the CE process.
- Attwel (2003) mentions that learning infrastructures are not just about computers and networks. Learning infrastructures have to include the ability to assess training needs and to respond to those needs. In V-CES project there is a gap when assessing the trainee needs which can be

responded by offering the services available within V-CES and new developments completed by this research.

- Blanchard and Tracker (2004) identify suitable training techniques for training knowledge and skills separately. There is no assessment reviewed in the area of cost engineering or cost estimating which identifies the knowledge and skills independently to direct the appropriate training techniques. The limitation from Blanchard and Tracker (2004) comes from the applicability of some of the techniques within the web-based environment defined by V-CES project. They have needed to be adapted.
- Even if other VLEs, as the one presented from Michau et al. (2001), have been successful, this study uses Moodle as the V-CES selected VLE to centralise all the related services in a single platform. European Schoolnet (2003) presented services that a VLE may offer. The service "*Diagnostic tools to provide some kind of 'intelligent tutoring' for personalized re-sequencing of content and assessment*" is seen as an interesting attribute for a VLE. Moodle does not offer the facility by which after an assessment of the trainee competences it suggests the suitable e-training material. This research addresses this capability.

2.3 Cost Estimating

Cost estimating is a key tool when making business decisions and yet it is a challenging task due to its complexity. This section introduces the main features of cost estimating to justify the challenging aspect of helping the cost estimator to create cost estimates.

The kernel of this study is the understanding of the CE process. Therefore, a special emphasis is made on examining the three CEMs: analogy, detailed and parametric. This allows the definition of the knowledge and skills required, and the identification of areas where the mentoring can enhance.

One of the areas where intelligent mentoring is deployed is in the suggestion of the CEM. The section concludes by analysing and comparing the criteria proposed by different sources when deciding the CEM to use.

2.3.1 Cost Estimating, a Challenging Task

Cost estimates are "*the art of approximating the probable cost or value of something, based on information available at the time*" (SCEA, 2006). Cost estimating is the first stage and function of cost engineering.

It is noticed that the market pushes companies to improve on quality, flexibility and the variety of products (among other factors) whilst also reducing costs. Data concerned with costs must be considered.

Cost estimates are needed in different stages of the product life cycle. But it is during the design period at which around 80% of the final costs are committed and so it is at this particular stage when they can have the largest impact. Being conscious about realistic cost value at this stage in the life cycle can help to prevent future financial disasters. Both overestimating and underestimating will reduce the chances of producing the product at a minimum final cost.

Some initial questions must be resolved before beginning an estimate such as, what method to use. This is a compromise between accuracy and availability of the data as time is often limited. One of the most challenging issues in CE is the availability of data. The lack of information must be handled by the cost estimator who must manage the situation and propose a solution.

Cost estimators have to work with techniques and/or software to develop an appropriate approach to this complex task. They are demanded to possess experience and knowledge in identifying sources of information, evaluating engineering information, identifying the correct CEM to use and creating/using cost models. It is usually necessary to acquire an understanding of the manufacturing processes.

Many authors (Asiedu and Gu, 1998; DeMarco, 2005) have pointed out the need to do realistic estimates. As shown in Figure 2-3, both under and over-estimating projects could lead to disaster. When costs are underestimated, you may face situations of insufficient resources (staffing, scheduling, machine processing, tooling, etc.) to accomplish the project, resulting in panic decisions and unrealistic expectations. This incurrence to not budget for costs represents eventual increases of costs. Overestimating, instead of resulting in greater profits, reflects Parkinson's Law application: "the money is available, it must be spent". You may face the under-use of resources and excess capacity, so not being competitive when pricing and the loose of orders.

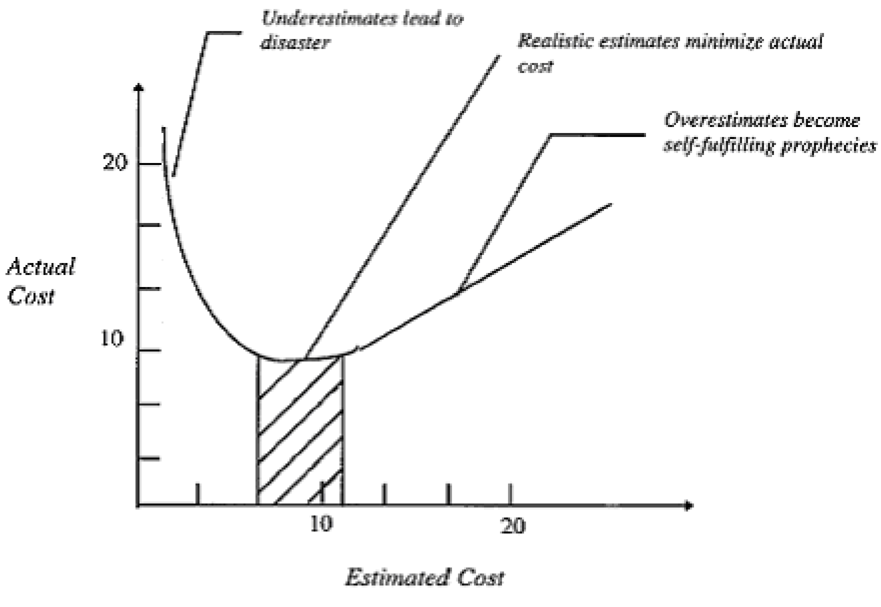


Figure 2-3 The Freiman curve (Asiedu and Gu, 1998)

Literature review has shown that the commercial software tools are cost models (fixed packages) based on a single CEM or a combination of them. Main ones are listed as following:

- Price software (www.pricesystems.com, PRICE H, PRICE LC) addresses the parametric CEM.
- Galorath (www.galorath.com, SEER H, SEER SEM, IC and DFM) addresses parametric and detailed CEMs in a single cost model.
- Boothroyd & Dewhurst (www.dfma.com) address a cost model combination of parametric and detailed.

2.3.2 Cost Estimating Methodologies

Since the 1950's, in an effort to improve estimating consistency and speed, researchers and practitioners have been applying engineering principles to develop cost models (Hamaker, 1994). Today, there are several types of cost models such as: parametric, analogy, detailed (bottom-up) and more recently the use of artificial intelligence is being used in the development of cost models (Asiedu and Gu, 1998; Curran et al., 2004). Different tools and applications have been built in order to produce with quantitative results for the cost estimate. However, there is a lack of formalisation in the procedure and material used during the cost estimation. There is a difficulty for others to understand a final estimate if they can not comprehend the rationale and the assumptions underlying an estimate (Rush, 2002). All the documentation used during the process has to be reflected and stored. In brief, an explicit definition of the CE process and the inclusion of the information required could bring benefits in terms of:

- Helping to train others.
- Allowing a better understanding of the estimate during negotiations with customers.
- Allowing a better justification in front of colleagues within the company when deciding to review or reuse a cost estimate.
- Allowing a better reuse of an estimate.

This study focuses on the first benefit: Helping to training others. SCEA (glossary) offers the following classification of the CEMs:

Detailed: is characterised by a thorough, detailed analysis of all tasks, components, and assemblies. This type of estimating produces requirements for labour, tooling, and material items.

Analogy: is based on historical cost data of a similar (analogy) item and utilizing adjustment factors to account for complexity, technical, or physical differences between the items.

Parametric: is a technique which employs one or more Cost Estimating Relationships (CER) for the measurement of costs associated with the development, manufacture, and/or modification of a specified end item based on its technical, physical, or other characteristics.

SCEA (2003) defines ten and NASA twelve steps to conduct when developing a cost estimate (see ANNEX L). V-CES has established a CE process by analysing the steps proposed by the SCEA (2003), the model proposed by NASA (2004) and the information gathered from many companies involved in the automotive, aerospace and semi-conductor equipment manufacturing sectors. The nine steps obtained are the following, which are called activities (V-CES Consortium D2.4, 2005):

[STEP 1] Receive Customer Request
[STEP 2] Define Work Breakdown structure
[STEP 3] Create Cost Analysis Requirements description (CARD)
[STEP 4] Select Cost Estimating Methodology
[STEP 5] Create/Select Cost Model
[STEP 6] Create Cost Estimate
[STEP 7] Develop “What if” analyses
[STEP 8] Document cost estimate
[STEP 9] Present cost estimate

Step 6 is where one of the three CEMs is implemented. The three of them have the following high level tree relation (main activities):

- Definition of work packages (WPs)

- Estimate Cost of each WP
    - Definition of the Product Breakdown Structure (PBS)
    - Estimate cost of individual components
- WP overhead cost.
- Estimate overhead costs.

The difference within the previous tree relationship among analogy, detailed and parametric comes from the component level, 'Estimate cost of individual components', this is where the component cost is obtained by using different cost methodologies. The CE process and the CEMs considered and defined by V-CES are an input of the research.

2.3.2.1 Analogy

The analogy based (or case-based) requires the identification of the similarities and differences of items, the identification of a reusable case, and its adaptation if necessary (V-CES Consortium D2.4, 2005).

The effectiveness of this methodology depends heavily on the ability to identify and quantify correctly the complexity, technical, or physical differences between different components. This technique involves a high degree of expert judgement (Curran et al, 2004). This can be also seen as a limitation as it relies on the judgment and experience of the analyst/estimator.

The analogy CEM in the V-CES process is applied in STEP 6, once the analogy CEM has been selected in step 4, and it has the following steps:

- Definition of work packages (WPs)
- Estimate Cost of each WP (see Figure 2-4)
    - Definition of the System Breakdown Structure (SBS, analogous to PBS) – with just new components (which an analogous component has to be defined).
    - Estimate cost of individual components
        - Identify new components.

  - Identify and collect prior system data.
    - Data sources.
    - Design Data.
    - Manufacturing data.
    - Cost Data.
    - Normalisation of data.
  - Develop cost factors (requirement differences, design differences, design maturity and technology maturity).
  - Develop new system component cost improvement slope (optional).
  - Develop productivity improvement factors (optional).
  - Collect all factors and calculate new system cost.
- WP overhead cost.
- Estimate overhead costs.

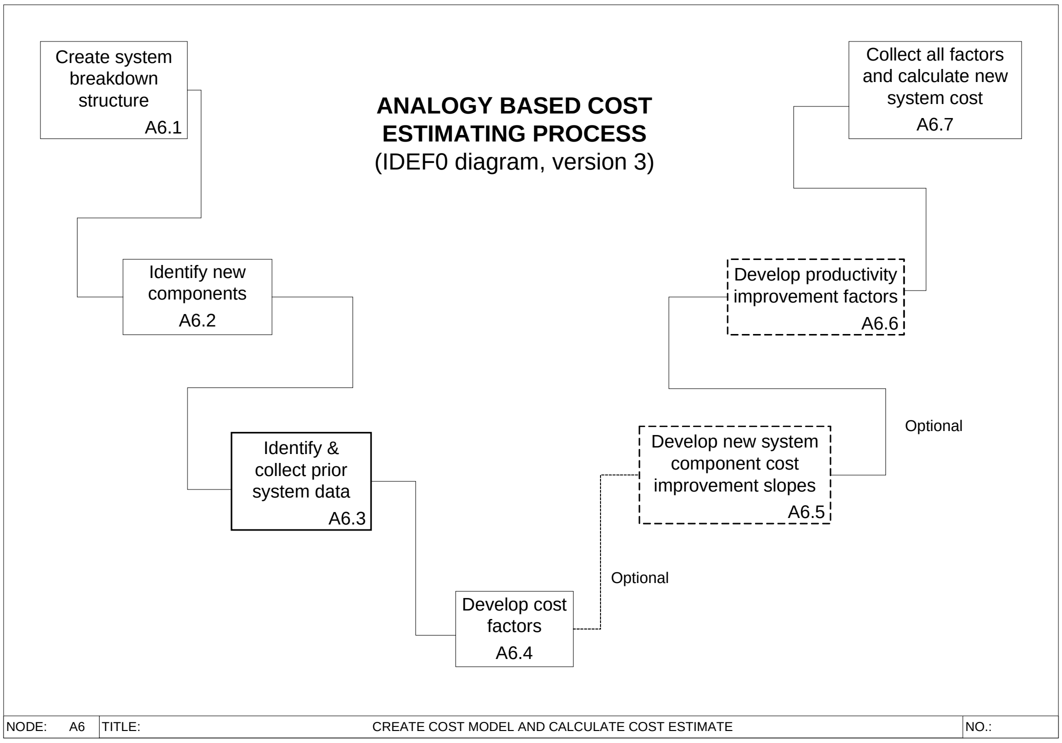


Figure 2-4 Analogy CE process IDEF0 diagram (simplified) (V-CES Consortium D2.4, 2005)

2.3.2.2 Detailed (or bottom-up)

The detailed methodology, also known as bottom-up and grass roots, demands access to detailed cost data and the allocation of the cost elements mainly: labour, material and equipment. In V-CES, it is applied as a unit-based cost system, and it is characterised by a thorough, detailed analysis of all the components and processes related to them (V-CES Consortium D2.4, 2005).

The detailed CEM in V-CES process is applied in STEP 6, and it has the following main steps (see the process in deep at (V-CES Consortium D2.4, 2005)):

- Definition of work packages (WPs)
- Estimate Cost of each WP
    - Definition of the Product Breakdown Structure (PBS)
    - Estimate cost of individual components
        - Material cost
        - Processes
            - The labour cost
            - Equipment cost
            - Process overhead cost.
        - Component overhead cost.
- WP overhead cost.
- Estimate overhead costs.

2.3.2.3 Parametric

This CEM is based on the identification and mathematical formulation of relationships between cost and product parameters (cost drivers), known as Cost Estimating Relationships (CERs) (V-CES Consortium D2.4, 2005). These parameters may be physical attributes, performance, specifications, or functions (Kwak and Watson, 2005). Within the aeronautical industry, for example, mass relates to the cost of production and so as the weight of the aircraft increases so does the cost of producing it (Roy and Sackett, 2003). Another example could be the relationship or correlation between the number of design drawings and the cost of the design process for a large aircraft assembly (Curran et al, 2004). This approach demands the access to historical data and assumes that the relationship will continue in a similar way in the future (V-CES Consortium D2.4, 2005).

Algorithms can be developed for more complex CERs, providing industries with a widely used technique to predict the costs of developing products throughout the lifecycle. Parametric estimating is a successful technique to predict cost, although the estimator must ensure that common sense and expert judgement are not overlooked by statistical data (Coley, 2005).

The steps of the parametric CE process defined by V-CES are the following:

- Definition of work packages (WPs)
- Estimate Cost of each WP
    - Definition of the Product Breakdown Structure (PBS)
    - Estimate cost of individual components (see Figure 2-5)
        - Define Estimating Hypothesis
        - Identify data requirements
        - Collect relationships data
        - Evaluate and normalize data
        - Analyze data for candidate relationships.
        - Perform statistical analysis.
        - Test relationships and analyse correlation.
        - Select Cost Estimating Relationships (CERs)
        - Populate model and calculate cost
- WP overhead cost.
- Estimate overhead costs.

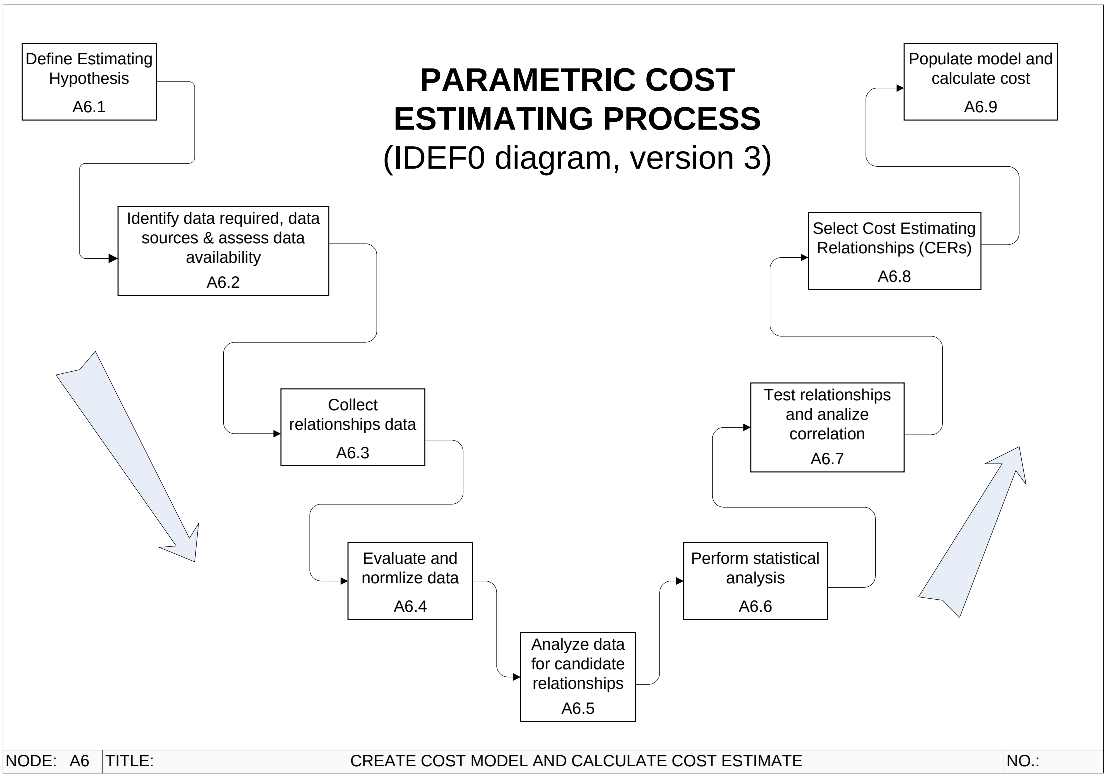


Figure 2-5 Parametric based CE process IDEF0 diagram (V-CES Consortium D2.4, 2005).

2.3.3 Selection of the Cost Estimating Methodology

Once the different CEMs addressed by this thesis (analogy, detailed and parametric) are defined, the characteristics of CEMs could make one CEM more suitable in application than the others. In other words, which criteria should a cost estimator apply in order to decide upon the CEM to use for a particular situation?

According to NASA (2004) there are four activities associated with the selection of the CEM:

1. Determine the type of system being estimated.
2. Determine the life cycle phase of the project.
3. Determine the availability of data.
4. Select the Cost Estimating Methodology/ies.

The goal of this set of tasks is to select the best CEM (or a combination of CEMs) to develop the most accurate cost estimate possible according to the characteristics and constraints of the situation.

2.3.3.1 Presentation of different authors view

Different authors and sources define which CEMs are more suitable according to the stage of the project life cycle and which other elements may influence the CE selection.

Various organisations provide an Estimate Classification in which each class is identified with a series of characteristics. Understanding these characteristics leads to the possible definition of the most suitable CEM to use.

AACE International (2004) addresses the suitability of the CEM by classifying the estimates in five classes. The five characteristics used by the AACE recommended practices to classify the estimates are:

- Level project definition (main characteristic to identify the class)
- Typical end usage
- Suitable CEMs
- Estimating accuracy
- Preparation effort.

Table 2-2 shows the characteristics for a generic Cost Estimate per class (generic industry) defined by AACE International (2004).

Table 2-2 Generic Estimate Classification Matrix (AACE International, 2004)

	Primary Characteristic	Secondary Characteristic			
ESTIMATE CLASS	LEVEL PROJECT DEFINITION Expressed as % of complete definition	END USAGE Typical purpose of estimate	**METHODOLOGY** Typical estimating method	EXPECTED ACCURACY RANGE Typical variation in low and high ranges [a]	PREPARATION EFFORT Typical degree of effort relative to least cost index of 1 [b]
Class 5	0% to 2%	Screening or feasibility	Capacity Factored, **Parametric Models**, Judgement, or **Analogy**	4 to 20	1
Class 4	1% to 15%	Concept Study or Feasibility	Equipment Factored or **Parametric Models**	3 to 20	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	**Semi-Detailed** Unit Costs with Assembly Level Line Items	2 to 6	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	**Detailed** Unit Cost with Forced Detailed Take-Off	1 to 3	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	**Detailed** Unit Cost with Detailed Take-Off	1	5 to100

Notes:
[a] If the range index value of “1” represents +10/-5%, then an index value of 10 represents +100%/-50%.
[b] If the cost index value of “1” represents 0.005% of project costs, then an index value of 100 represents 0.5%.
[a] and [b] are relative values to what is named 1.

ANSI Standard z94.0 uses 3 classes of Estimate Classification, the Association of Cost Engineers (AcostE, UK) 4 classes and the American Society of Professional Estimators (ASPE) 6 classes.

NASA (2002) Cost Estimating Handbook suggests that the CEM to be selected depends upon the type of system being estimated and the data considered. It proposes five key elements to be considered:

- Schedule: “when is the estimate due?”
- Resources: “how many estimators are assigned?”
- Data: “how much information is available?”
- Expectation: “what exactly does the customer want?”
- Phase of the program

Curran et al. (2004) note that traditionally, there are two main estimates: (1) a first-sight estimate early on in the design process; and (2) a detailed estimate that is associated with precision costing.

Many authors comment on the suitability of the 3 CEMs: analogy, detailed and parametric, in general terms based on the stage of the project lifecycle. Figure 2-6 depicts a diagram with the Life Cycle Project Phase considered by NASA (2002) and Figure 2-7 shows the appropriate CEM during different program phases.

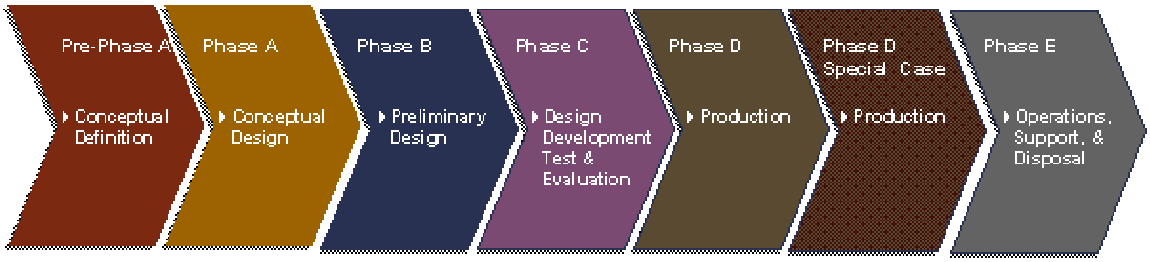


Figure 2-6 Life Cycle Project Phase (exhibit 3.2, NASA, 2002)

The handbook describes each phase in terms of; the requirements, information available and purpose. Then it links it with the most suitable CEM and techniques.

Figure 2-7 shows how the three CEMs: parametric, engineering build-up (detailed) and analogy are related with the different phases. In the description of the phases, it is mentioned that:

- For pre-phase A the most effective CEM is either a parametric or analogy.
- For phase A you may start considering to construct your own model using the more specific data and engineering build up estimates from the project participants.
- For phase B you start to move away from parametric and analogy methodologies used when little information is available, and move toward more detailed parametric estimates or engineering build up (or detailed) estimates.

For phase C and D, when actual data is available, the preferred CEM is engineering build-up (or detailed).

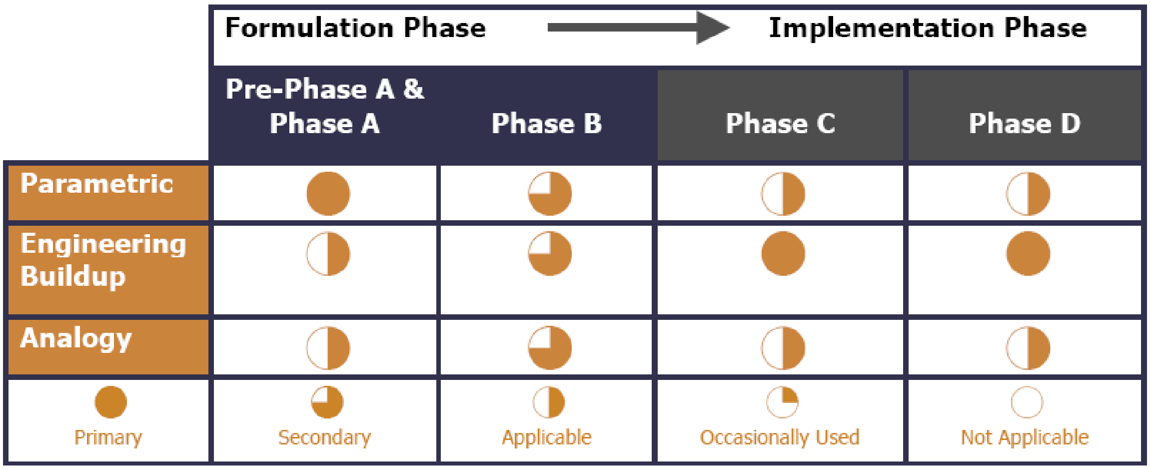


Figure 2-7 Selecting a CEM is influenced by Program Phase (NASA, 2002)

Rush and Roy (2000) present a table matching the stages of the project lifecycle with the three CEMs: analogy, detailed and parametric (see Table 2-3).

Table 2-3 Product lifecycle vs. 3 CEMs: parametric, analogy and detailed (Rush and Roy, 2000)

Cost Estimating Techniques **USED WHEN:**	**PE (parametric)**	**CBR (analogy)**	**Detailed Cost Estimation**
Concept design phase (innovation)	✓	✓	✗
Concept design (similar products)	✓	✓	✗
Feasibility Studies	✓	✓	✗
Project definition	✓	✓	✗
Full Scale development	✗	✗	✓
Production	✗	✗	✓

There is an agreement when referring to parametric as to make use of this CEM during the early stages of the project lifecycle, when limited data and technical definition is available and some lack of precision is accepted (Curran et al, 2004; Asiedu and Gu, 1998; Kwak and Watson, 2005).

In analogy, there is also an agreement to make use of it during the early stages of the project lifecycle, when there is insufficient design/cost data or time to perform a detailed cost estimate. Curran et al. (2004) point out the Federal Aviation Administration (FAA) Life Cycle Cost Estimating Handbook recommendation to use analogy for a new product or systems that is primarily a combination of existing sub-systems, equipment or components for which recent and complete historical cost data is available.

Analogy methods are often used when a parametric model or other estimating algorithms (capacity factor, equipment factor, etc.) cannot be applied; because of the lack of adequate historical data to develop the algorithms or the project differs significantly from the projects that existing algorithms can address (Dysert and Pickett, 2005).

As presented, the CEM used for any particular estimate depends on many factors. Table 2-4 shows a summary of them:

Table 2-4 Summarise of the factors that influence the CEM selection

AACE International	NASA
- Design information on hand. - Data available.	- Data (ex. availability of usable historical data, detail of technical definition)
- Amount of time available to prepare the estimate.	- Schedule (time, time according resources)
- End use of the estimate.	- Expectation
- Amount of money available to prepare the estimate. - Estimating tools.	- Resources (experience and skill level of personnel, budget)
- Level of project definition.	- Phase of the program
	- Maturity of the program
	- Scope of the effort to be estimated

It can be concluded that parametric and analogy can be used in early stages of the project lifecycle, when the project definition is limited. There is not much data available and a certain percentage of inaccuracy is accepted. There is not a clear distinction between parametric and analogy just considering the variable stage of the project life. Some authors tend to first use analogy and then parametric and some otherwise. The main factors that influence the decision is the type of data and the resources (people and estimating tools) available. The detailed methodology requires a high amount of information, this can only be achieved when the project definition is advanced, i.e. the later stages of the projects life cycle, but as a result of this, a detailed estimate generates results with better accuracy.

2.3.3.2 Accuracy

“Estimate accuracy is an indication of the degree to which the final cost outcome of a project may vary from the single point value used as the estimated cost. Estimate accuracy tends to improve (e.g. the range of probable values narrow) as the level of project definition used to prepare the estimate improves” (AACE International., 2004) (see Figure 2-8).

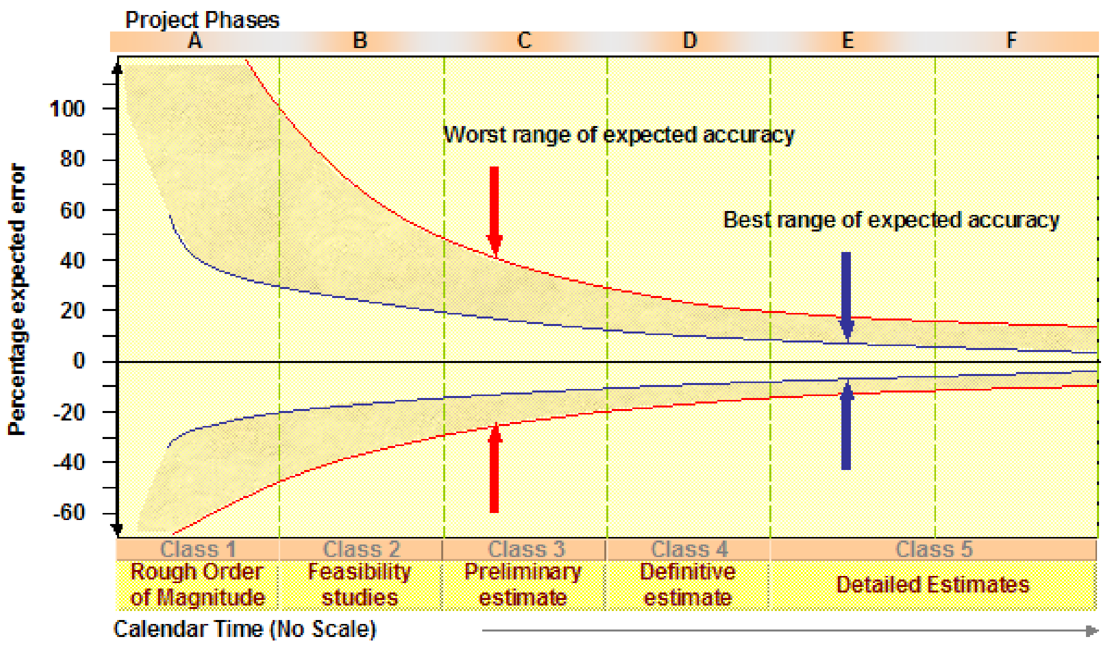


Figure 2-8 Accuracy along the project life cycle (AACE International., 2004)

Leading to the idea that both under and over-estimating are not desirable, Asiedu and Gu (1998) state that the achievement of a good accuracy of the cost estimates is very essential to the survival of an organisation. Good estimates are not only essential for external use (e.g. contract bidding) but also for internal use (e.g. cost control, budgeting).

In Table 2-5, factors influencing the accuracy of a cost estimate are presented from various sources:

Table 2-5 Summary of the factors that define the level of accuracy expected

SOURCE	Factors that influence the accuracy
AACE International (2004)	- Level project definition. - Quality of historical cost data (used when developing factors and algorithms). - Judgement and expertise of the estimator. - State of the new technology in the project - Estimating techniques employed. - Level of effort budgeted to prepare the estimate. - Desired end use of the estimate.
Oberlander and Trost (2001)	- Who was involved in preparing the estimate? - How the estimate was prepared. - What was known about the project? - Other factors considered while preparing the estimate.
Dysert and Pickett (2005)	- Level of scope information available that can be expected from the level of scope information available. - Available information. - Estimating tools and techniques available to support the estimate.
Roy (2003)	- The kind of product. - Who was involved in the creation of the estimate - How the estimate was done - The data available at the time of creation that basically depends on the product design stage where the estimate is developed.

From an owner's perspective, if the cost estimate is not accurate, the financial return from the capital investment may not be realised; and compounding this problem is the fact that other deserving projects may not be funded. From a contractor's perspective, accurate estimating is just as important because of profit margins, the possibility to repeat business and maintain their reputation (AACE International., 2004).

However, the estimator must be clear to identify the level of accuracy that can be expected according to some factors or characteristics of the CE situation. The term expected or appropriate accuracy has also been mentioned by Dysert and Pickett (2005) and Hamilton and Westney (2002).

Apart from these general factors, several references suggest different accuracy values according to the sector or industry. AACE International (2004) published percentage values of accuracy for the ‘process industries companies’ (involved in manufacturing and production of chemicals, petrochemicals, and hydrocarbon processing) as relative factors for the generic industry (see ANNEX E). Percentage values could be suggested for the industries: automotive, aerospace and semi-conductor equipment manufacturing (which where targeted when defining the CE process).

Table 2-6 collects the expected accuracies from different sources: AACE, ANSI Standard z94.0, ACostE (for ‘process industries companies’) and Creese and Moore (1990). The values do not specifically target the automotive, aerospace and semiconductor equipment manufacturing sectors, but they can be used as a reference.

Table 2-6 Table with accuracies from different sources (AACE International, 2004)

AACE Classification Standard	**AACE (2004)**	**ANSI Standard z94.0**	**Association of Cost Engineers (UK) ACostE**	**Creese and Moore, 1990**
Class 5	L: -20% to -50% H: +30% to +100%	Order of Magnitude Estimate -30%/+50%	Order of Magnitude Estimate Class IV -30%/30%	Early planning and conceptual stage: -30%/+50%
Class 4	L: -15% to -30% H: +20% to +50%	Budget Estimate -15%/+30%	Study Estimate Class III -20%/30%	System design process: -15%/+30%
Class 3	L: -10% to -15% H: +10% to +30%		Budget Estimate Class II -10%/10%	
Class 2	L: -5% to -15% H: +5% to +20%	Definitive Estimate -5%/+15%	Definitive Estimate Class I -5%/5%	Detailed design stage: -5%/+15%
Class 1	L: -3% to -10% H: +3% to +15%			

2.3.4 Key Observations and Limitations

None of the sources reviewed propose a tool which by requesting data it analyses and provides feedback on the CEM to use. There is no system suggesting the CEM. Possible reasons could be:

- Difficulty to be more specific in the recommendation criteria for the CEM and still providing generic rules independently on the sector, company or product.
- Most of the software tools focus on a single cost model which can be built with one or many CEMs. Cost estimator has already compromised the CEM when a CE tool is used.

NASA (2004), AACE International (2004) and FAA Life Cycle Cost Estimating Handbook (2002), define and explain the factors which influence the CEM selection in a generic way. It would be interesting to break these factors into particular needs for each of the CEM.

These needs can be identified from different sources, but some limitations are seen; needs are not all contained in one single source, they are not explicitly defined (it is required to analyze the CE process and CEM manuals) and some parameters are defined for particular industrial sectors.

To deploy such a system it is requested to identify sensible but relevant number of questions to the user to avoid reducing the user answer and to have enough information to make the decision. Therefore, information presented to the user has to be specific and easy to read. Michau et al. (2001) state that e-training modules have to meet requirements of length and assessment practicality.

For the 'project life cycle stage' factor, NASA (2004), AACE International (2004), Rush and Roy (2000) have matched the three CEM: analogy, detailed and parametric with the stages of the project life cycle. NASA (2004) is providing qualitative (text) and AACE International (2004) quantitative (in a table) description of the project life cycle stages.

The ‘data’ and ‘resources’ factors have to be also identified. Sources who analyse them are NASA (2004), FAA Life Cycle Cost Estimating Handbook (2002) and ISPA/SCEA Parametric Estimating Handbook (2003) which provides qualitative descriptions (text) throughout all the CE process for the 3 CEMs targeted: analogy, detailed and parametric.

The material regarding this area, as defined before, is contained in many different sources and spread mostly in a qualitative format (text), within manuals such as NASA (2004), FAA (2002) and AACE International (2004). The relevant parameters have to be selected and presented to the user. A rule-based system analysing the inputs will reduce bias (ex. conformability with some CEM) and complexity to analyse the situation (leading to a less time consuming process).

NASA and FAA are mostly targeting the aerospace sector and AACE International the Civil Engineering sector. V-CES project is addressing the manufacturing sectors, in which automotive should be also represented. The information used from these sources is validated with participants from the automotive sector as FIAT and external consultants.

2.4 Cost Estimator Knowledge and Skills

To assess the trainee needs, the identification of knowledge and skills required for the understanding of the CE process should be conducted. Skills and knowledge of a cost estimator are considered in different frameworks such as: qualifications, certifications and competences.

Firstly, this section covers the different qualification and certifications related with the cost estimator. Secondly, the competences related with cost estimating are reviewed from the literature, different sources are analysed and compared with the requirements of this research.

2.4.1 Qualifications and Certification for Cost Estimating

Taking into account that cost estimating is a major area in cost engineering, “the route to becoming a cost engineer is vague and informal” (Grant, 2004). “Cost engineers and cost estimators can be characterised as professionals with an educational background ranging from medium level vocational training to university degrees, with different professional experiences prior to their involvement in cost practices, mainly in manufacturing, design, management or accounting. They are involved in other activities apart from cost estimating itself, but also part of the cost engineering discipline, for example: risk analysis, value analysis, cost modelling, design to cost, etc.” (Rush et al, 2003).

The US department of Labour (2006) refers to the training and qualifications status of the cost estimator by saying that it depends on the industry. When defining the manufacturing industries, it seems that employers prefer to hire individuals with a degree in engineering, physical science, operations, or a related subject. A great emphasis is placed on experience involving quantitative techniques.

Organizations representing cost estimators, such as the AACE, SCEA and the ACostE, also sponsor educational and professional development programs. In 1990, for example, AACE (2004) devised a model masters degree with emphasis in Cost Engineering based on the “Required Skills and Knowledge of Cost Engineering”. UK Ministry of Defence has the Ordinary National Certificate as a normal minimum of engineering qualification for entry to the Cost Engineering function (Grant, 2004).

Specialized courses and programs in cost estimating techniques and procedures are offered by many technical schools, community colleges, and universities. They can be offered as a part of the degree in civil engineering, industrial engineering, and construction management or construction engineering technology. There is no a recognised undergraduate degree. Cost estimating is a significant part of many master's degree programs in Construction and Cost Engineering. Cranfield University, for instance, is offering a post graduate qualification in Cost Engineering.

USA certifies hundreds of cost engineers/estimators every year through different organisations. The certification scheme basically consists of establishing the body of knowledge required and then validating it with the individual's knowledge. To become certified, the estimator has to demonstrate a number of years of experience, pass an examination and in some cases have some articles or papers published in the field. AACE addresses the construction professionals, SCEA the defence and aerospace contractors and manufacturers, and ISPA focuses on parametric estimating. In UK, the only organisation who provides a certification scheme is the ACostE. Grant (2004) presents some of the main reasons why USA schemes are much more successful than the UK schemes.

A professional certificate can be valuable to cost estimators because it provides professional recognition of the estimator's competences and experience. In some jobs the certification may even be a requirement. Grant (2004) points out that his thesis contributes to knowledge with a tool which integrates the person, the training framework and the certification. He developed a Passport System based on the Cost Engineering skills and competences required, the professional experience, the background and the training needs.

This section has been defined to present the possible qualification and certification programs related with cost estimating. It can be concluded that there are few recognised academic qualifications defined to become a cost engineer, and even less for a cost estimator. The certification in cost estimating has not been addressed by this research.

2.4.2 Cost Estimator Competences

The use of a competency-based approach has been used for many years. The usefulness of this approach has different benefits. The most two relevant applications are related with employment, assessing the candidates for a specific job and employee development (used for example to justify the salary based on the level, position and acquisition of the competences), and training. Other benefits could be the use of competences when defining certificate schemes. Human resources may base their decisions using this system/tool as an effective approach, as much as the program based on competences is suitable to the organisations needs (e.g. correct identification and assessment of the competences).

2.4.2.1 What are competences?

Presented below are some definitions of **competence**:
(1) "*a broad grouping of knowledge, skills, and attitudes that enable a person to be successful at a number of similar tasks*" (Blanchard and Tracker, 2004).
(2) "*ability to do something well or effectively*" (Collins Cobuild English Dictionary, 1995)

(3) "*the quality or extent of being competent*", being competent: "*having the necessary skill or knowledge to do something successfully*" (Askoxford, 2006).

Definition of competence number (1) is the one used in this thesis and it has been the key driver for this research. Knowledge, skills and attitudes are defined from different sources as the main elements that compound a competence (see Figure 2-9).

V-CES (V-CES Consortium D1.5, 2005) definitions are:
Skill: is "the knowledge and ability that enables a person to carry out an activity properly/right: 'What to do and when'".

Knowledge: “information and understanding about a subject that a person has”.

Knowledge is categorised with three elements (Blanchard and Tracker, 2004):

- Declarative: “*The information we acquire and place into memory*”.
- Procedural: “*Understanding of how and when to apply the declarative knowledge*”.
- Strategic: “*Awareness of the procedural and declarative knowledge, how it was learned and how can be applied to achieve a specific goal*”.

Being **skills** (Blanchard and Tracker, 2004):
“The capacities needed to perform a set of tasks that are developed as a result of training and experience.”
Skills are dependant on knowledge in the sense that the person must know “what” to do and “when” to do it. However, a gap separates knowing those things from actually being able to “do” them.

Attitudes:
“Employee beliefs and opinions that support or inhibit behaviour”

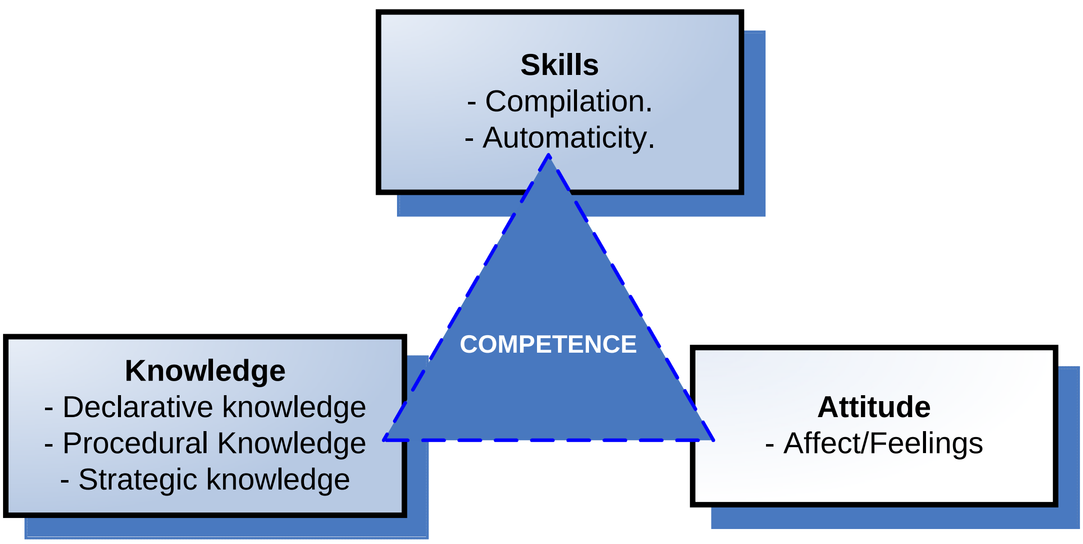


Figure 2-9 Definition of competence (Blanchard and Tracker, 2004)

Attitudes are important issues for training because they affect motivation. Motivation is reflected in the goals a person chooses to pursue and how hard they work achieving those goals (Blanchard and Tracker, 2004).

The attitude issue is not directly addressed in this research as it involves pedagogical requirements that are out of the scope. Through the contact between trainees and mentors it is possible that trainees acquire certain attitudes from the mentors, but this issue is not going to be undertaken in this study. However, the attitude is indirectly considered when defining the approach under the assumption that, in order to keep a good attitude and motivation on the trainee, the first basis is to develop an application/system which the trainee finds useful and comfortable to use.

Experience is considered as:
"knowledge or skill in a particular job or activity which you have gained because you have done that job or activity for a long time" (Collins Cobuild English Dictionary, 1995)

2.4.2.2 Definition of competences

Many qualifications are now based around definitions of competence for specific roles, the most famous of which are NVQs (http://www.pd-how2.org/2_9.htm#DC), National Vocational Qualification (NVQ), with the National Council for Vocational Qualification (NCVQ) as the leading body. Other organisations have also worked on the definition, accreditation and assessment of competences, such as Standing Conference of Associations for Guidance in Educational Settings (SCAGES), National Educational Guidance Initiative (UDACE) and Training Enterprise and Education Directorate (TEED), formerly the Training Agency (Grant, 2004).

Different literature and organisations have proposed a list of competences for a cost estimator or a cost engineer (cost estimating being the core function of a cost engineer (Grant, 2004)).

Grant (2004) establishes the competences of a Cost Engineer by identifying 287 skills from 15 different sources (Department of the Army Cost Analysis Manual, US Department of Labor, DoD Industrial Specialist training program, Naval Center Cost Analysis, Pricing & Forecasting Group (UK MoD), AACE Model Master's Degree program, SCEA certification, Iowa State University, AACE certification study guide required skills and knowledge, Rolls Royce (UK), ISPA parametric book, DoD Parametric Cost Estimating Handbook, Capability Improvement Model for Cost Engineer, Navy Acquisition and Capability Improvement Model for Cost Engineer) and a survey. The 287 were rationalised and combined to a list of 132. Finally they were grouped into 9 clusters. Cost Estimating is considered a cluster which gathers the core skills and competences. The rest of the 8 clusters collect supporting skills and competences for the Cost Engineer (see Table 2-7).

Table 2-7 Cluster defined by Grant (2004) defining the skills required for a Cost Engineer. (*)Clusters to be considered to have impact in the CE process

Skill Clusters	Number of Skills
Core Skills	
Cost Estimating (*)	32
Supporting Skills	
Manufacturing and Engineering (*)	9
Project Management (*)	12
Commercial Awareness	12
Financial & Accounting (*)	15
Industrial Engineering (*)	7
Business Awareness	21
Inter-Personal	15
Improvement Activities	7

The Pricing and Forecasting Group (2002) within the Ministry of Defence (MoD) has developed a side where the competences for different clusters are presented, such as technology management or earned value management.

The two clusters related with cost estimating have been identified:

- Cost Engineering Functional Competences.
- Cost Forecasting Competences.

The AACE International (2004) resumes in an annex (D.6) the competences of a Cost Engineer. One of the sections is Cost Estimating, although they are general and not in depth enough to characterise the CE process. For each competence there is a set of questions (assessing knowledge) and tasks (assessing skills) required in order to possess that competence.

US Department Labor (2006), Hammaker (2000) and Dysert and Pickett (2005) define the technical and personal competences of the cost estimator. Mishra et al. (2002) identify ten knowledge types (being commercial [C] and engineering [E] classified) as being essential for CE experts.

As mentioned before, the selection and definition of competences may have different purposes. The definition of the list of competences is not an objective of current research, but it is an important element within the research framework. The purpose is not to define the competences for the cost estimator, but to identify needs in the understanding of the CE process and CEM to suggest suitable training material and tailor the E-mentor tool (from V-CES). In order to test the framework within the cost estimating area, the need to use a list of competences to achieve a correct validation was perceived. Two options were considered:

1- Use an existing list of competences for Cost Estimating.

2- Create own list of competences.

The different lists of competences (or skills or knowledge) previously presented does not exactly fulfil the requirement to target the understanding of the CE process focused on the three CEMs: analogy, detailed and parametric. Two main reasons are:

- Not all the competences as a cost estimator are believed to be able to be trained using the online environment defined as a framework of the research. Although it is accepted that when performing the job of a cost estimator, skills related with interpersonal or business issues are required, they are not directly involved in what is defined as the main driver of the research: the understanding and undertaking of the CE process.

  Parry (1996) mentions that the major difference among competency studies conducted by different organisations is whether ‘competences’ include or exclude personality traits, values and styles. He supports the idea of being aware of its need for job success but in general he does not consider them competences to be developed through training. Human resources experts believe that training programs should focus on performance and not on personality.
- The level of deepness in the definition of competences. When referring to the process, it is necessary to consider this as the major input for the CE process. This is the set of activities to be accomplished. Therefore, some competences would be missing.

Grant (2004) list has been identified as the only who really targets the CE process and CEM. This research makes use of the collecting, identifying and grouping effort of the competences made by Grant (2004). The list has been modified for the following reasons:

- It has been shortened to specifically target the CE process for the 3 CEMs: analogy, detailed and parametric and in order to be able to relate all the competences to the rest of the framework.
- Lack of description annexed to the competence name could make difficult the inclusion and justification of some of them.

The competence list in this research is defined with the understanding of the CE process, the list of competences defined by Grant (2004) and the validation with individual CE expertise. This list can be extended or modified according to new requirements following the research approach presented along the thesis.

If the requirement was to deliver certification programs or establish national qualification on cost estimating (or cost engineering), as is the purpose of cost estimating organisations like AACE or universities, then an homogenization of the criteria of which competences are required could be the best approach. This was the approach followed by Grant (2004).

2.4.2.3 Competency-based approach for online training

There are many web tools available that provide a competency-based framework to establish the competences you require and link them to learning or recruitment services (e.g. http://www.predaptive.com/elearning.htm). This helps the user (customer) in deciding the competences, for example using 360º techniques and matching it with the training material provided by the user.

The Ministry of Defence (MoD) has developed a web-side where the Acquisition Training and Development Directory (Pricing & Forecasting Group, 2002) is deployed. It defines clusters which contain competences (e.g. cluster "Cost Engineering" has the Competence "Effective use of Cost Engineering experience and techniques"). For each competence, a list of formal Training, Reading, Distance/Interactive, e/learning and work experience is provided.

2.4.2.4 Level of competence

There is a consistency in the way competency levels are grouped within the Cost Engineering community and other engineering disciplines. The purpose is to classify and measure the individual's performance. Different organisations and sources define the competence level from 3 to 5 classes:

- UK OGC (2004) proposes a five level structure (Not required/tested, Awareness, Knowledge, Expert and Innovator) in its publication Successful Delivery Skills Programme.
- The Pricing & Forecasting Group (PFG) (2002) (within MoD) is using three levels: Basic, Practitioner and Expert.
- NASA (NASA, 2002) uses three levels with slightly different PFG terms.
- Grant (2004) uses the same five levels as OGC.

Each of the levels contains a definition which can be individual or common for all the competences to assess.

2.4.2.5 Assessment of the level of competences

In any profession, competence requires to be measured as much objectively as possible. This implies to define the assessment process to avoid confusions or misunderstanding and to try to quantify it in a reasonable way.

The assessment of competences within The Pricing & Forecasting Group (2002) is done by reading the level description mean for each competence. After this the user selects the level.

Grant's (2004) assessment is completed by reading a generic description of the cluster (where generic knowledge and skills are defined) which contains the competence and the generic description of the levels (common for all the competences). After this the user selects the level.

The OGC (2004) has developed a framework which management competences are described and broken down in terms of knowledge and behaviours (linked to skills). This approach is used as one of the key points for the research framework. Table 2-8 shows a full example for the competence: Quality management.

Table 2-8 Approach of the OGC for management competences

Competence	***Quality management***
Definition	Quality management is concerned with the commitment to delivery and control of quality at all stages of the project's implementation. It requires responsibilities to be defined and delegated, and monitoring and reporting systems to be in place.
Knowledge and understanding implied "As an *expert* you will have underpinning knowledge and understanding of"	• Principles of and processes for quality assurance and control • Quality assurance approval authorities • Communication and presentation techniques.
Behaviours. "as an expert you will be able to"	• verify quality assurance procedures are appropriate and sufficient to meet requirements • ensure a commitment to quality assurance procedures is obtained from those responsible for applying them • ensure data is gathered and recorded in accordance with agreed quality assurance procedures • accurately assess outcomes and performance against specified or expected targets or milestones • identify areas of non-conformance promptly and report them clearly to those who need to know • initiate effective remedial action to correct the causes of non-conformance and limit their effect produce and maintain records in line with requirements needed for quality audits.

2.4.3 Novice and Expert

The grading systems used by organisations such as OGC (UK) or MoD (UK) is presented in section 2.2.3.4. The terminology can then be related with the novice and expert classification. Some of them are: practitioner, expert or innovator. All of them include the words knowledge, skills and experience, but none of them focus on the classification by differentiating knowledge from skills.

Definition of novice and expert can be found from literature.

Flyvbjerg (2001) defines a 5-level human-learning process from novice to expert:

a. Novice
b. Advanced beginner
c. Competent performer
d. Proficient performer

e. Expert

"Novice, as an individual who experiences a given problem and a given situation in a given task area for the first time, recognises facts, characteristics and rules independently of the context. *Expert* behaviour is intuitive, holistic, and synchronic, understood in the way that a given situation releases a picture of problem, goal, plan, decision, and action in one instant and with no division into phases" (Flyvbjerg, 2001).

Rush (2002) defined a practical hands-on approach for acquiring knowledge (KEN) which defines knowledge as the "gap" between a novice and an expert when facing a solving problem. Novice and expert are defined as following:

- Novice: "The author, who had a limited understanding of how experts produced their cost estimates, and therefore, relied on the expert's knowledge".
- Expert: "A person who has background in the subject area and is recognised by his or her peers or those conducting the study as qualified to answer the questions"

The current research and thesis does not use any of these definitions, as the grading system is based on the possession of knowledge and skills. The definition of novice and expert moves from knowledge to skills required to carry out a cost estimate based on the CE process.

2.4.4 Key Observations and Limitations

Currant (2004), US Department Labor (2006), Hammaker (2000), Dysert and Pickett (2005), AACE International (2004) and The Pricing & Forecasting Group (2002) have identified lists for cost estimators but they do not focus on the CE process. Grant (2004) proposed a list of skills for a Cost Engineer where there is a cluster for Cost Estimating. It has a special emphasis in the CE process although the direct use of the list is restricted to the understanding of all the skills (as no description is provided) and direct applicability to V-CES service. The list has been adapted to the CE process and validated with CE expertise.

The limitations for the current research on the assessment of competences within The Pricing & Forecasting Group (2002) are the fact that it relies on the users' perception when selecting the level after reading the competence level description and the lack of focus on the CE process and CEM. In Grant's (2004) assessment, the fact that the user is provided with knowledge and skills for the cluster and not for each competence demands from the user; specific knowledge of which kind of knowledge, skills, experience and attitudes are expected in each competence topic. This brings added subjectivity to the assessment system done in PFG, although the competences are more suitable for the research approach.

The OGC (2004) has developed a framework which management competences are described and broken down in terms of knowledge and behaviours (linked to skills). This approach is used as one of the key points for the research framework. The limitation is that it has not been developed in cost engineering or cost estimating.

From the literature reviewed, none of them establishes the level of competences classification based on the differentiation from knowledge and skills, although all of them include the works: knowledge, skills and experience in some way. This differentiation may result in being useful to propose suitable training methods as defined in section 2.1.2.

Grant (2004) defined a framework to assess the competences with potential to be linked with training material as future work. A possible way of linking the assessment with the training material is described in this thesis. The e-training delivered by Pricing & Forecasting Group (2002) was limited in content targeting the CE process and the CEMs.

2.5 Intelligence Web-based Applications for Training Purposes

"*Cognitive studies or instruction have shown that learners must remain active and motivated. Learners must want to learn and be involved, active and challenged to reason about the material presented. Flashy graphics and simulations are not enough; the experiences must be authentic and relevant to the learner's work. Simple presentation of text, graphics and multimedia often result in systems that encourage passive learning and provide little, if any, adaptability to different learning needs. Interactive exercises are required that involve students in the material*" (Woolf et al., 2001).

To make the mentoring more flexible for the trainee needs, and the electronic environment used, the system makes some decisions or propose some suggestions according to the trainee interactions (inputs) to improve the learning process. This gives the adjective intelligent to the e-mentor.

Intelligence is defined as:
"Intelligence is associated with the ability to recognise patterns, apply experience and expertise to attend to solve problems, learn from new experiences and apply judgement when data are incomplete or unavailable" (Jayaraman and Srivastava, 1996).

Shen et al. (2001a) refer to intelligent mentor as offering intelligent advice or make an intelligent decision about a processing function. They state that a desirable characteristic, which many would consider fundamental, has the capability of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the enquirer.

Most of the literature found on intelligent e-mentor examples could be classified as Programmed Instructions (PI) or Intelligent Tutoring System (ITS) according to Blanchard and Tracker (2004). PI is the process of leading a trainee systematically through new information in a way that facilitates the most efficient learning. In its most basic level, PI provides the trainee with information, asks question, and based on the response goes to the next bit of information, and so forth. ITS uses artificial intelligence to assist the trainee. It does not only provide guidance and selects the appropriate level of instruction for the trainee, but also learns from its own process (what worked and did not work in the training of the trainee) and based on this information, improves the methodology for teaching the trainee. He also mentions that it consists of five components: a domain expert (or expert knowledge: set of knowledge about what is correct), a student model (storage of user performance), a training sessions manager (interpretation of trainee's responses and provide feedback), a scenario generator (determines the order and difficulty of the trainee problems), and a user interface (equipment allows the interaction trainee and ITS).

Most of the examples analysed consist of having a knowledge base and applying to some rule-based system (set of rules used to guide the trajectory of events). The areas addressed when analysing their work are:

(1) Guidance to the user through the process offering feedback and correction when required (e.g. you get a message when you do something wrong). [PI function]

(2) Delivery of more or less feedback according to the users learning evolution. The difference between (1) is that you keep track of user interaction/evolution (could be during the application or for future uses of the application). [ITS function]

(3) Based on user inputs and some knowledge, the system suggest/make some decisions relevant to the process to learn (could be the completion of an exercise, e.g. suggestion of methodology or training course in my study). [PI function]. The tutoring effect from here is to make transparent to the user the criteria applied on these decisions. This can be considered as a particular application from point (1).

Note: The approach of acquiring inputs and calculating a value using a particular formula or fix process is not considered. In this point any approach that does not consider rules or other kind of intelligence is not included.

(4) The definition of the process to follow is done by the user. They decide the way of doing it; no fixed methodology is followed (not approached by this study)

(5) Software (S) or web-based (W)

Table 2-9 Summary of the different type of intelligence for different ITS

	Geoffroy (2002)	Abersek (2004)	Jou (2005)	Patel (2001)	Khan {Khan 2002 #230 /d}	Shen (2001)
(1)	✓	✓	✓	✓	✓	✓
(2)	✓	✓	✗	✓	✗	✗
(3)	✓	✓	✓	✓	✓	✓
(4)	✗	✗	✗	✓	✓	✗
(5)	**W**	**S**	**W**	**S**	**S**	**S**

(Geoffroy et al, 2002): Virtual Assistant for Web-based Training In Engineering Education

<u>Field</u>: Mechatronics. Modelling and digital control of an electrical drive.

<u>Functionality:</u> Proposal of an Intelligent Tutoring System (Pascail, 2006) that integrates 3 agents: the Real Instructor (RI), the Real Assistant (RA) and the Virtual Assistant (VA).

(1) The aim of the VA is to provide feedback during the evaluation process to reinforce learning. They have developed a graphical interface called Cockpit. It is formed by the *experimentation console* (the interactive part to do the experiments) and the *Laboratory journal* (to document and report the observations and results).

When a group connects to the system for the first time, it is asked to complete a questionnaire to determine the profile of the group:

- Cognitive part (expert knowledge) based on personal information (e.g. names, address) and initial background (knowledge on the subject taught).
- Affective part (e.g. attention, rapidity, motivation, sound).

With the results from the questionnaire, the system assigns a ‘student group’.

The feedback provided depends on the student group in terms of the content and the required consultation, but the group can ask for more feedback at any time.

The evaluation is made by the RI, RA and VA.

(2) The VA checks different actions and updates the profile with the collected information (the update can be done by the group at any time). It stores information such as: number of errors before correct version, number of hints where the same error was detected, etc.

(3) The answers to the questions and the code written are checked against expected answers.

(4) No

(Abersek and Popov, 2004): Intelligent tutoring system for training in design and manufacturing

<u>Field</u>: Education in design, optimisation and the manufacturing of gears and gearing.

(1) Feedback is provided at the end of the process as a post-processor to interpret the results.

(2) During the process the students are encouraged to demonstrate knowledge and understanding, i.e., answer different questions. “The intelligent system is able to adjust the complexity of questioning and tutoring according to the student’s level of understanding”.

(3) The Pre-processor is used for user data entry (geometry, strengths, etc.). Knowledge bases store long-standing experience and theoretical knowledge in this field, which are connected to the ES (expert system). The solver is ruled-based.

Using a Genetic Algorithm, it is possible to optimise the design in terms of finding the better combination of parameters.

Parts:

- *Pre-processor: data entry (geometry, strengths, etc.).*
- *Solver: It generates the tooth flank shape, equations, etc. and a model.*
- *Knowledge bases.*
- *Post processor: interpretation of results.*

"During the process, the students are encouraged to demonstrate knowledge and understanding, i.e., answer different questions".

(4) No

(Jou et al, 2005): Development of an Interactive e-Learning System to Improve Manufacturing Technology education

Field: The creation of a virtual laboratory with graphical and interactive interfaces is implemented to train in the selection of process parameters, familiarization of machining tools and operations, Computer Numeric control (CNC) coding and simulations, etc.

(1) The system alerts the user when values are incorrect and provides some information to help the student to correct them.

(2) No.

(3) The system creates a code based on the geometric information specified and generate the manufacturing features and machining procedures required to fabricate the desired part. The possible machining procedures are also displayed. The system indicates the appropriate procedure and give the reasons for the decision making.

(4) No.

(Patel et al, 2001): Intelligent tutoring: from SAKI to Byzantium

Field: Teaching the concepts and skills of accounting.

It carefully designs the application according to the different stages of the cognitive skill acquisition (early, intermediate and late).

(1) Software is capable of identifying and giving partial scores for “incorrect interpretation but application of correct method”. Learner receives different kind of feedback depending on the number of attempts (incorrect answer). There are textual/graphical explanations and solved examples.
(2) The tutoring activity of the system is adaptive; with the improvement in performance there is less tutoring intervention.
(3) Rule based intelligence in guiding the user through the process and checking the answers provided by the user.
(4) The user does not force a learner to use a rigid sequence of data entry or a specific path to solution when multiple paths are possible. The system recognises all possible paths and alters its guidance in line with the path chosen.
This is a software application and as a new way of improvement, it suggests its implementation over the Web.

(Khan, 2002): Implement an intelligent tutoring system for adventure learning
Field: Deployment of a game environment and object-orientated user interface (OOUI) for teaching and learning. Players assume a particular role in a process industry and learn efficient operation of steam distribution system for conserving energy in the plant.

(1) The user has the option to decide either to receive interventions, review data sheets or not.
(2) Yes, but is not clear the way it is done.
(3) The intelligence applies in the selection of rules, formulation of models, search of solutions and simulation. The objects are capable of storing information about the move that a player makes in the form of lists and they can communicate to each other (by clicking in the graphical interface the user is directed to a specific place).
(4) No

(Shen et al, 2001a) “Developing an Intelligent System for Teaching Pre-Tender Cost Estimating of Office Building Projects” and (Shen et al, 2001b) “Intelligent multimedia for expertise-intensive training in construction”

Field: System to learn cost estimating of building projects in the conceptual design stages.

(1) Feedback and help is provided during the application.
(2) Second paper mentions that an additional feature that is incorporated in the development is to change over time according to the overall pattern on the interactions with the students. This feature does not only enable the system to react to the trainees according to a rule base, but also to record a training path and identify individual users’ learning difficulties in the structure and content of the training application.
(3) The inference engine is rule-based reasoning and is the same for both papers. The system requests answers to a few questions about the case, functionality, and appearance of the building as interface inputs. The knowledge base and the inference engine are used to minimize the number of questions to be asked, to implement codes and regulations for office buildings, to assess the complexity of the project and to decide the standards of finishes required.
(4) No.

2.5.1 Key Observations and Limitations

The literature review has identified the following key observations and limitations:

- There are many intelligent systems in other disciplines (see examples along the section 2.4), but no system has been found in the area of cost estimating or cost engineering. For example, Geoffroy et al. (2002) prove that the understanding of user’s needs and difficulties when using online applications has been really useful to support and encourage the user along the understanding of different process and concepts. This peace of work has been considered as interesting and relevant to this study as it tailors the feedback along the process with the figure of the Virtual Assistant (VA). The student model is identified with cognitive and affective profile. This research only addresses the cognitive part due to scope boundaries. According to this model and some questions during the application, the VA selects the type of feedback and when to propose it. The approach has been useful to demonstrate that the tailoring of feedback has succeeded for a particular project in ‘mechatronics’ which can be similarly applied in other areas. A challenged in the Cost Estimating area and within V-CES project is faced in this research.

- V-CES is providing a first layer of e-mentoring with the E-mentor tool which guides the user through a “step by step” process. The e-mentoring, as guidance and support, can be intelligent. The intelligence can be provided by analysing the data entered into the system, evaluating it through a rule-based system and providing feedback.

2.6 Summary and GAP analysis

During the project lifecycle many cost estimations have to be performed, not just one cost estimate per project. However, the methods used for its creation may differ because of the project characteristics and the life cycle stage of the project.

Literature defines that some CEMs are more suitable than others depending on certain factors. These factors have been presented during section 2.2 and then summarised.

Table 2-10 combines the main factors that influence the CEM to be used.

Table 2-10 Main factors for CEM selection

Factors influence CEM to be used
Level of project definition
Data available (historical, design, etc.)
End use (and Costumer expectations)
Resources (people, estimating tools, budget, etc.)
Schedule (time available)

It can be concluded that parametric and analogy methodologies can be used in early stages of the project lifecycle when the project definition is limited. There is not much data available and a certain percentage of inaccuracy is accepted. The detailed or bottom-up methodology requires a high amount of information. This can be achieved when the project definition is advanced in the later stages of the project life cycle. This can result in better estimating accuracies.

Many theoretical criteria for the selection of suitable CEM have been proposed, as presented during section 2-2. However, there is no system found in literature in which the user, by being requested some specific information, is suggested the most suitable CEM. Information required can be better defined if there is a good understanding of the CE process, and for this particular case, of the three CEM; analogy, detailed and parametric, some of the questions that arise are the following:

- How to quantify or define cost estimating in a more objective manner when deciding which CEM to use considering the different elements involved in a manageable and efficient way?
- Could the factors that influence the selected CEM be more specific? For example, considering the data and tools available, can they be better defined according to the CEM requirements?
- Addressing training purposes, can the reasons of the selection be presented and justified to the trainee?

Most of the online training in CE found in the literature operates in the same way. On the web page there is a list with all the available courses names or a browse to access them with key words. The criterion to get enrolled on them is to review its table of content, which specifies the different topics and in some cases, the type of material you can find in the course: quizzes, exercises, e-learning lectures, etc. But there is no suggestion of the e-training material based on the assessment of competences; which targets the training of knowledge and skills with particular training techniques. V-CES project and author literature have pointed out a lack in the e-courses content in the CE process and CEMs within the e-course. Current research and its developments have contributed to increase this content.

The assessment of competences within The Pricing & Forecasting Group (2002) is done by reading the description level mean for each competence and then selecting the level. The limitation of this method for the current research can be seen as it relies on the users' perception and it is restricted to the lack of focus on the CE process and CEMs. Grant's (2004) assessment is completed by reading a generic description of the cluster (where generic knowledge and skills are defined) which contains the competence and the generic description of the levels and then deciding in which level the user is. This demands from the user; specific knowledge of which kind of knowledge, skills, experience and attitudes are expected in each competence topic. This also brings subjectivity to the user assessment.

The OGC (2004) has developed a framework which management competences are described and broken down in terms of knowledge and behaviours (linked to skills). This approach is used as one of the key points for the thesis framework. The limitation of its use is that it does not cover cost engineering (or estimating) competences, it only does in management competences.

Many of the intelligent systems related with e-training purposes found in the literature review focus on the need of feedback and guidance through different processes (most of them involved exercises) as a requirement for any mentoring approach. Some of them store the trainee's interaction to tailor and improve the learning and helping process. The techniques that are used in this study are not innovative, but they have not been applied in the cost estimating domain with the purpose of understanding the CE process.

The gaps in knowledge, which validated the research, attempt to fill and provide:

- An intelligent framework and tool to suggest the suitable CEM out of the three targeted: analogy, detailed and parametric.
- An intelligent framework and tool to suggest the suitable e-training courses which integrates the following specifications:
    - Assessment of the level of competences based on a grading system that focuses on a differentiation of the knowledge and skills acquisition.
    - Identification of the e-training material according to the acquisition of knowledge and skills and being aware of the electronic environment.
- Development of an intelligent e-mentoring system to offer guidance and feedback along CE process as defined by V-CES.

3 Research Aim, Objectives and Methodology

The previous chapter presents a review of the literature. It examines what has been published within the field of Cost Estimating to support the understanding of the CE process. It first introduces concepts such as learning, training and mentoring as approaches, to provide help and understanding. Next review on the three main CEMs: analogy, detailed and parametric, enables to understand the areas where the cost estimator can be helped. This leads to the definition of knowledge, skills and competences for a cost estimator. Intelligent web-based training tools have been also analysed. The literature review is finally used to summarise and highlight a gap in the research.

This chapter defines the research aim and objectives pointed out after the literature review process. The deliverables are exposed as a contribution on the strategy. The methodology and flow diagrams are presented with the deployable techniques.

3.1 Aim

The aim of the research is to:

"Develop an <u>intelligent e-mentoring</u> service on product cost estimation, focused on manufacturing. This e-mentor has to facilitate the learning process of the trainee needs, based on his/her competences and on the cost estimating process to be used".

The main research questions to be answered are the following (Figure 3-1):

- Why intelligence is required for the cost estimating e-mentor?
  (*Why intelligence is required?*)
- In what could intelligence be incorporated within the e-mentor?
  (*In what could intelligence be incorporated?*)

- What is the nature of intelligence required?
  (*What kind of intelligence?*)

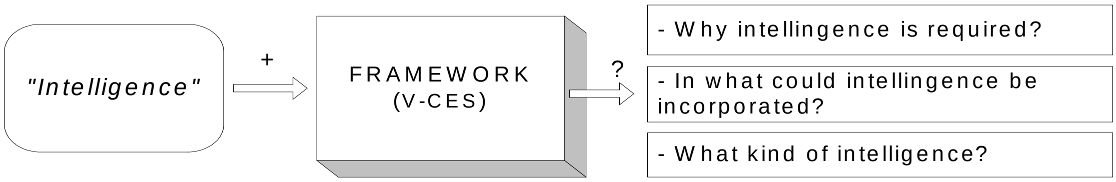


Figure 3-1: Research questions to be answered in the short format

3.2 Objectives

In order to achieve the central aim of the study, “to develop an intelligent e-mentoring service”, it is necessary to break it down into the objectives for the research.

- To suggest the effective Cost Estimating Methodology/ies to be used by the trainee, referring to the three Cost Estimating Methodologies considered in the project: analogy, detailed and parametric.

- To provide guidance in the e-training path required by the user.
  - Identify the trainees’ current competences and target competences.
  - Monitor a system to propose the suitable e-training material according to the level of competences.

- To provide guidance in how to conduct the Cost Estimating process.
  - To identify how to characterise a novice and an expert within the research approach.
  - To establish a flexible guidance user interface during the Cost Estimating process based on the novice/expert approach.

- Validate the research work that carried out through a number of case studies.

3.3 Deliverables

The final deliverable of the thesis is the result of the research as described in the methodology section (section 3.4). The thesis covers the literature reviewed, deep analysis of the research content (V-CES) and proposes different areas where intelligence can be applied.

The main focus and deliverable of the research is the implementation of the different areas where intelligence can be applied within the research context development (E-mentor and VLE side). These tools allow cost estimators, both novices and experts, to improve their performance when carrying out cost estimates. The aim of this is to provide guidance and support to the various stages along the CE process.

Finally, it is intended to publish a journal paper where the thesis is introduced as new areas of development within the research context (V-CES) and a second journal paper detailing the primary findings of the research and presenting the developments. The author has been involved in the writing of a conference paper for V-CES.

3.4 Research Techniques and Methodology

To conduct research, it is necessary to select and define a structured and rationalised approach. This helps the author when planning and carrying out the study as well as, credibility when validating and receiving feedback along the process.

The following sections address the approaches and techniques available and specify which have been used according to the research requirements. The methodology in this thesis is presented.

3.4.1 Available Research Approaches

In general there are two approaches used by researchers; Robson (2002) calls them ‘fixed’ or ‘flexible’. Other researchers call them ‘quantitative’ or ‘qualitative’ respectively (Burns, 2000). It also can be classified as ‘deductive’ and ‘inductive’ (Robson, 2002).

A fixed design strategy calls for a tight pre-specification before you reach the main data collection stage. If a design cannot be pre-specified, a fixed approach cannot be used. The data in this approach is almost always in the form of numbers or numerical format (Robson, 2002).

A flexible design evolves during data collection. The data is typically non-numerical, usually in the form of words. The flexible design uses three main sub-approaches: Case Study (development of an in-depth analysis of a single case or multiple cases), Ethnography (describing and interpreting a cultural and social group) and Grounded Theory (describing a theory grounded in data from the field) (Robson, 2002).

3.4.2 Selecting a Research Strategy and Methodology

The selected research approach is a mixture of the fixed and flexible approaches as it is pre-specified before the data collection process but it admits certain flexibility along its evolution.

3.4.2.1 Research techniques

The research techniques used to obtain and validate the data are interviews and case studies, which are all described by Robson.

Interviews

Interviewing typically involves receiving answers from the participants. The choice of the technique usually depends on the depth of knowledge required. The study uses semi-structured interviews as it contains some characteristics of the fully structured interview and some of the unstructured interviews.

A fully structured interview is common to the quantitative research, when objectives are predetermined and data is relatively easy to analyse using tested statistical methods. This is usually combined with closed-questionnaires to obtain known answers. Unstructured interviews are often used to obtain descriptive data. The interview is not predetermined and is subject to the interviewer and interviewee interaction process. This is usually combined by open-questionnaires which can be flexible or even improvised. (Robson, 2002)

In this research, the first interviewing stage happens when first contact with a new interviewee to obtain their professional and educational background is made. This is carried out with a fully structured interview together with a closed-questionnaire.

The rest of the interviews are semi-structured for the following reasons:
The structure of the interview is always predefined. It contains an initial stage where the aims of the study and the interview are presented to the participant; and a final stage when summarising what has been done and future feedback if required. The questionnaires are defined to reduce the number of open questions as much as possible. The target is the use of as much close questions as possible to facilitate the analysis process by themes and for comparison (Robson, 2002). However, in areas where further explanation may

be required, open questions are added to support and justify the close questions. The unstructured component of the interview process is coming from further explanations on the objectives of the study, the approach/framework and the relevant issues that may appear during the meeting.

For each of the questions in all the questionnaires, the target is explicitly defined to ensure the requirements are achieved.

Interviewing can be time consuming. Robson (2002) suggests specifying and communicating the length of the interview to the interviewed. He also mentions that lasting less than 30 minutes is unlikely to assess correctly and longer may be unreasonable for busy interviewees. Interviews are conducted as part of the research for this thesis and are mostly semi-structured and conducted on a face-to-face individual basis.

Case Study

The case study method is useful for research that involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence (Robson, 2002).

The main limitations or risks of the case study are:

- Validity: in terms of the degree that a theory, model, concept, or category describes reality (Gummesson, 1991). Robson (2002) discusses three categories to qualitative research: reactivity (the way the researcher's presence may interface), respondent bias (for example trying to answer what they think the researcher wants to listen to) and researcher bias (assumptions or preconceptions that the researcher brings to the situation).
- Reliability: relates closely to the replication that is, if two or more people study the same phenomenon they should reach the same results (Gummesson, 1991). In case studies, researchers focus on dependability

and whether the results make sense and are agreed up on all concerned (Burns, 2000).

- Generalization: concerns the characteristics of research findings that allow them to be applied to other situations.

The main strategies the thesis will use to overcome or minimize the risks are (Robson, 2002):

- Prolonged involvement (minimising the reactivity and respondent bias but it can increase the researcher bias).
- Triangulation (the use of two or more sources of data collection helping to reduce the risk of validity and improves reliability)
- Member checking (returning the material obtained to the respondents),
- Audit trail (keeping a full record of the activities carrying out the activities, it increases validity and contributes to reliability).

3.4.2.2 Methodology

The methodology followed in this study is represented in Figure 3-2. Because of author involvement on the context of the present study (V-CES), an initial gap on the context is identified. This is leading to identify initial areas where intelligence could be incorporated within the E-mentor and VLE side. Literature is reviewed (published books, journals and other papers) to point out what has been completed in these areas and to acquire knowledge and understanding on how the approach could be done (see Figure 3-2). As the context of the research is web-based, Internet World Wide resources are also investigated to see existing online services for training purposes.

After this process, the gap is fully accepted and defined. The areas where to apply intelligence are defined and used as drivers when presenting the structure of the methodology.

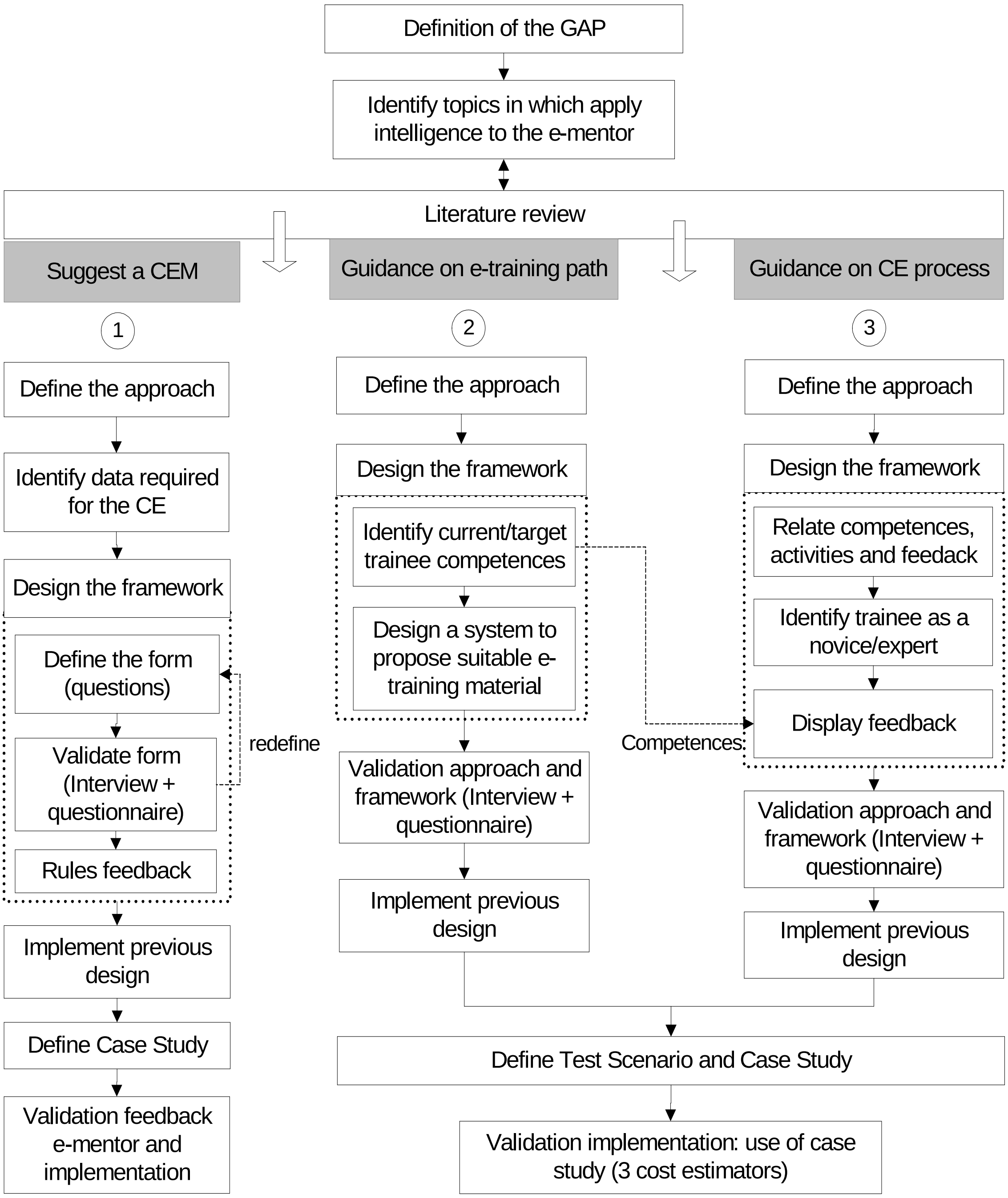


Figure 3-2: Methodology followed by this research

The methodology is broken down into three main directions of research (see Figure 3-2) which directly link to the achievement of the objectives:

- Suggest a Cost Estimating Methodology (CEM).
- Guidance of e-training path.
- Guidance on the Cost Estimating (CE) process.

Each of the three directions begins with the definition of the approach. This focuses on which purposes and objectives want to be achieved. It defines a high level definition of the framework.

The first interviewing stage takes place prior to any first participant contact with the aim of identifying the professional profile (both academic and work experience). The professional profile enables to understand, evaluate and discuss the outcome of the interviews.

The three directions are explained from the design of the framework.

Suggestion of the Cost Estimating Methodology (see Figure 3-2, part 1):
The literature review serves to provide the information required for each CEM. This covers the first level of validation, as information used comes from relevant organisations such as AACE, SCEA, ACostE or MoD. Using this data as part of the framework, self-completion questionnaires are prepared to be filled each time the trainee wants to do a cost estimate and requires some help in the selection of the CEM.

The validation of the approach focuses on the usefulness of the CEM being suggested. The validation of the framework targets the content of the self-completion questionnaires and the feedback received. The interviews used are semi-structured with eight experienced cost estimators (average with more than 10 years) supported by questionnaires (with open and closed questions). The interviews and questionnaires focus on analysing real examples of projects the cost estimators experienced during their professional lives to see if they are well described by the system.

As there is a need to combine research with practice in the real world, a case study is defined with an experienced cost estimator (more than 10 years experience) in order to validate the framework with a ‘complete’ real project.

This is a similar exercise done in the eight previous interviews but the project is analysed in deep throughout the project life cycle.

Suggestion of the e-training path (see Figure 3-2, part 2):
From the literature review and Internet sources, different methods are observed and analysed leading to the definition of the research framework in identifying the trainee current and target competences. Both approach and framework are validated through semi-structured interviews supported by closed questionnaires (with punctual open questions to justify a close question answer). The interview helps introducing and clarifying the use and purpose of the service. Closed questions target specific issues to validate. Feedback received from the interviewed cost estimators is the basis of redefining the framework prior to starting the implementation phase.

Within the framework definition, questionnaires and quizzes (test of knowledge) are used to get the information requested from the user. The type of questionnaire is self-completion and highly structured, cutting down open-ended questions to a minimum and trying not to ask directly for the competences but instead, asking for characteristics that imply having these competences. Quizzes focus on testing particular concepts of knowledge. The questions on the online application are close as; they are easy to answer for the user and easy to analyse for the system.

After validating the approach and framework, the framework is implemented.

Guidance on the CE process (see Figure 3-2, part 3):
The identification of the trainee as a novice/expert is possible by using the information from:

- Literature review.
- Assessment of competences completed in line of research 2. This is why there is a link called competences between lines of research 2 and 3 (see Figure 3-2).

Within the gap and the validation of the approach, the demand to receive help during the CE process was pointed out from the participants in V-CES.

The implementation of the framework covering the areas, of ‘Suggesting e-training path’ and ‘Guidance on the Cost Estimating (CE) process’, is validated after the creation of a test scenario. The development of the content of the framework is out the scope of the research. However, representative elements are selected to be fully developed according to the framework description. This is what has been called a test scenario. The test scenario is accomplished by obtaining information from relevant organisations such as NASA or ISPA/SCEA and CE expertise. The implementation of the test scenario is used to validate the prototype through a case study.

Three cost estimators are selected to perform the case study as an exercise to see how suitable and useful the approach is in a situation close to reality.
The case study has 2 parts:
Part 1: Assessment of the competences of the trainee. Three competences are fully developed within the test scenario, but only one is required to be assessed using the system assessment.
Part2: Defining the trainee as novice or expert and selecting one activity within the CE process.

The main limitation when carrying out individual case studies, and in the case of the elaboration of the test scenario, is time to gain access to companies and to perform the exercise with them. This limitation can be overcome by doing preliminary studies and being really organised when carrying out the interview process.

The methodology to carry out the case study takes place with one person (a trainee) at each time. Methodology steps:

- Explanation of the purpose of the case study and how to access and use the application.

- Performing the case study as an exercise.
- Semi-structured interview (or self-completion questionnaire when not possible) of perception with closed questions (to focus on particular issues such as if he/she has understood or realised something during the process) and open questions (to get the general perception of him/her). This is critical as feedback is required from the trainee.

The professional profile of the individual participants throughout the research developments is presented in Table 3-1, which will be referred along the thesis when mentioning the interviewees involved in the different activities.

Table 3-1 Professional profile of participants in the thesis development considered as users (see ANNEX A)

	Job Background	Cost Estimator Experience								Education	Teaching Experience	
		Experience (years)	Sector	Method. Used			Cost Model		Cert. on CE		Years	Subject
				D	A	P	Own design	Com. Sft.				
User 1	Management	> 10	Aerospace.	Yes	Yes	Yes	Yes (D, A and P)	No	No	Eng.	6-7	Aeronautic / Systems Engineering (Quenn's University Belfast)
User 2	Manufacturing	> 10	Aerospace, Defence.	Yes	Yes	Yes	Yes (D and P)	Yes	Yes (ACostE, ISPA Cert.)	Eng.	1	Cost Estimating (in AcostE)
User 3	Cost Management	> 10	Automotive	Yes	Yes	No	Yes (A)	No	Yes (AcostE)	Eng.	0	x
User 4	Manufacturing	3-6	Aerospace, Defence.	Yes	Yes	Yes	Yes (P)	Yes	No	Eng.	0	x
User 5	Manufacturing, Management	> 10	Aerospace	Yes	Yes	Yes	Yes (D and P)	No	Yes (AcostE)	Eng.	0	x
User 6	Management	> 10	Automotive	Yes	Yes	No	Yes (D)	No	No	Econ.	0	x
User 7	Management	> 10	Semicond. Equipment	No	Yes	No	Yes (A)	No	No	Eng.	0	x
User 8	Manufacturing	3-6	(*)	Yes	Yes	Yes	Yes (fuzzy logic, P)	Yes	No (PhD)	Eng.	2	Master Degree by Research in Cost Engineering
User 9	Design, manufacturing	< 1	Metallic components	Yes	No	No	Yes (D)	No	No	Eng.	3	> Mechanical Engineering >Computer Science

	Job Background	Cost Estimator Experience								Education	Teaching Experience	
		Experience (years)	Sector	Method. Used			Cost Model		Cert. on CE		Years	Subject
				D	A	P	Own design	Com. Sft.				
User 10	Manufacturing	1-3	Semicond. Equipment and metallic components	Yes	Yes	No	Yes (D and A)	No	Yes (AcostE)	Eng.	0	x
User 11	Design & manufacturing	1-3	Aerospace	Yes	Yes	Yes	Yes (D, A and P)	SEER-H	No	Eng.	3	Cost Estimating Software
User 12	Manufacturing	> 10	Defence	Yes	Yes	Yes	Yes (D, A)	No	Yes (SCEA Certificate Cost Estimator/Analyst)	Eng.	3	Risk management, Hardware Estimating, Overhead Analysis
User 13	Manufacturing	1-3	Plastic components, other (electronic equipment)	No	Yes	No	Yes (Using Analogy excel spreadsheet)	No	No	Engineering	0	x
User 14	Manufacturing, Design, Management.	No	NA	NA	NA	NA	NA	NA	NA	Engineering	5	Mechanical Engineering (science, design, materials, HNC+degree)

Key: D=Detailed, P=Parametric and A=Analogy. (*) Automotive, aerospace, defence, plastic components, metallic components, composite components

3.5 Summary

In this chapter following the identification of a gap in research, several objectives are set. The approaches to be followed in order to fulfil these objectives; are discussed and justified and a research methodology is designed. This is developed using the literature review, surveys, interviews and case studies.

The next chapter addresses the framework, development and validation. It presents the framework, which is the context of the research and the motivation to develop it. The development fully details the characteristics and performance of the solution. The validation process is exposed as well as, how the outcome has been used to redefine the framework.

4 An Intelligent e-Mentoring Service Framework

The previous chapter details the strategy used in terms of the research aim, objectives and deliverables. The methodology is explained and drawn using a flow diagram. Objectives can be reflected through the methodology. Research techniques selected are also presented and linked to achieve the inputs, validation of the approach, framework and implementation.

This chapter addresses the intelligent e-mentoring service framework for Cost Estimating. The framework, development and validation are presented. The framework is placed into the research context following into the motivation which is presented. The development fully details the characteristics and performance of the solution. The validation process is exposed as well as, how the outcome has been used to redefine the framework.

4.1 V-CES Framework

Prior to the definition of the areas of work, it was essential to consider the context and framework of the study. As mentioned in chapter 1, the research has been based on the V-CES project. This configured the starting point and provided some of the boundaries.

The inputs or starting points of this study are showed in
Figure 4-1.

The inputs are:

- The IDEF0 diagrams of activities for the CEMs: parametric, detailed and analogy (see section 2.3.2).
- The IDEF1X diagrams of the database linked to the CE processes.
- The training material is already developed (organised in courses).

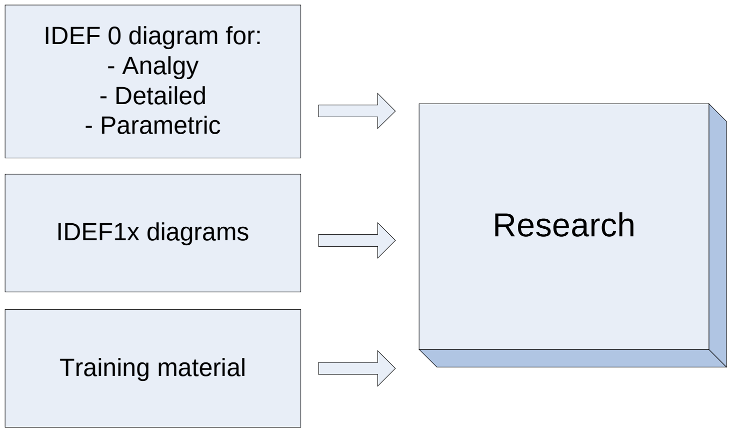


Figure 4-1: Positioning of the Research

4.2 Motivation of the Framework

Chapter 3 presents the three research questions (see Figure 3-1). The first question asked is; "why intelligence is required?" which responds to the motivation of the framework and it will be covered in this section. It is important to consider the research context presented in the previous section to fully understand the motivation. The third question is; "what kind of intelligence?" is introduced at the end of the section as a top level explanation.

V-CES has deployed two top level resources to train cost estimators (see Figure 4-2):

- Platform where the training material is deployed (mainly courses).
- Cost Estimating E-mentor.

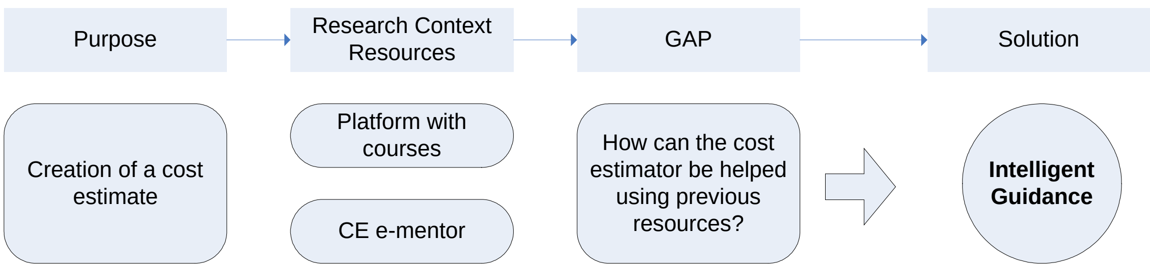


Figure 4-2 Why intelligence is required?

With these resources available, is it possible to bring the current system any form of intelligence in order to help the estimator to carry out the cost estimate? Thanks to the understanding of the V-CES project and the literature reviewed, the author identified that it was possible to bring intelligence in terms of guidance in different areas.

4.2.1 What Kind of Intelligence?

The question "what kind of intelligence" is looking at answering two questions:

- Is it possible to detect when the trainee could be helped and in which way? How?

  Should any insights of measurement be implemented in order to; to classify the trainee (cost estimator) or the cost estimation to be measured and their requirements identified?
- How to respond to these requirements once the previous question is answered?

The intelligence applied has been mostly based on a <u>production rule-based system</u> based on assessing the <u>interactions</u> between the application and the user. The intelligence is seen as feedback in terms of **support** and **guidance**.

The areas or topics where guidance and support could have been provided, followed by the areas that were finally developed, are presented in section 4.3.

4.3 Development and Description of the Framework

The Intelligent e-Mentor framework has evolved through the research. The initial framework was developed based on literature review and user validation reports for the V-CES service. Then the framework was improved through a number of validation sessions with cost estimating experts and novices for the usability of the service. This chapter presents the expert validation of the structure and content of the framework. The usability of the framework was tested after the implementation.

The areas where intelligence could have been applied within the research context (V-CES) are discussed at the early section. Following, the areas that have been developed are presented.

Intelligence could have been implemented at two different levels:

1- Guidance or advice in the e-training path needed by the user.
2- Guidance in how to conduct the cost estimation process.

1- Guidance or advice in the training path needed by the user

This approach relies on a high level of e-mentoring. Current and target competences of the trainee in cost estimation should be identified. The trainee needs and interests could be assessed, by knowing the current and target (desired) level of competences.

If these interests are cross referenced within a matrix, where the competences are related with the e-training courses available, the e-training path can be proposed (see Figure 4-3).

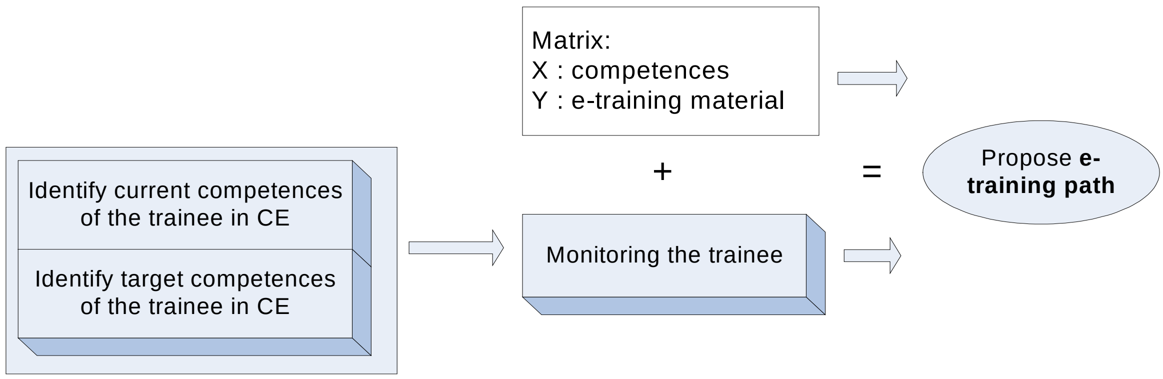


Figure 4-3: Scheme on how to propose the e-learning path

2- Guidance in how to conduct the CE process

This approach relies on a low level of e-mentoring. It focuses on the process using the CEMs: detailed, analogy and parametric. Two different sub-approaches can be reached:

2.1- *Guidance User Interface (GUI)*

This approach considers a way to present the methodology to the trainee according to if he/she is recognised as novice or expert:

- Tailoring the help provided in terms of: quantity, type and moment to present it.
- Having a general overview of the process.
- Request the information differently: number of parameters, screen and presentation of information (e.g. novice may require more steps than an expert. This is something pointed out in the validation of the project).

2.2- Suggestions during the CE process

During the CE process many different decisions have to be taken: from selecting the CEM to producing and evaluating learning curves.

2.3- *Process and activities*

In this case, the purpose is that the user builds their own methodology according to their needs. This would imply the redefinition of the processes or methodologies. The application could be formed by different modules which are activities, entities that make sense by themselves. Some of them could be placed in different positions within the methodology and some others with respect to an order of precedence.

This study has focused on the development of the work described in points above 1, 2.1 and 2.2 because of the balance between the time and effort required and the available for this one year study. In section 2.2 the suggestion of the CEM is addressed. This has been seen as a relevant topic for any estimate not addressed with a tool.

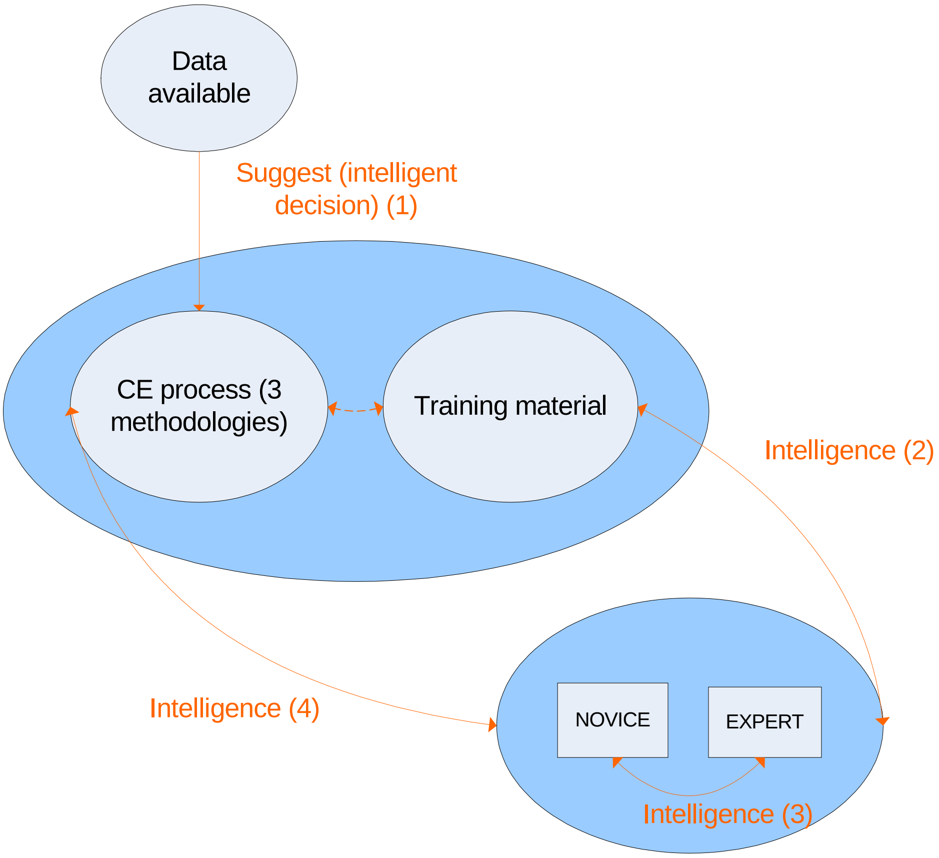


Figure 4-4: Areas in which intelligence has been applied

As a summary, Figure 4-4 depicts the specific areas in which intelligence has been incorporated, the relationship to each other (as an integrate platform) and their position within the global frame of the research. The research question, “In what could intelligence be incorporated?” presented in Figure 3-1 is then answered. There is a control according to whether the trainee is novice or expert and at which moment a novice can be considered an expert (intelligence 3 in Figure 4-4). Depending if the trainee is considered a novice or expert, intelligence is applied in the guidance through the CE process (intelligence 4 in Figure 4-4) and in the suggestion of e-training material (intelligence 2 in Figure 4-4). Intelligence in terms of guidance is also considered in the suggestion of the CEM (parametric, analogy or detailed) according to the data available for the cost estimate (intelligence 1 in Figure 4-4). Training material and CE process (3 CEM) are linked as help material during the CE process can be based on the training material.

4.4 Suggestion of the Cost Estimating Methodology

The suggestion of the CEM is one of the areas where intelligence has been deployed (intelligence 1 in Figure 4-4). The aim of this section is to present the framework to suggest the CEM to use when estimating the cost of a particular project or product.

After the literature review stage, it was concluded that the main factors that influence the CEM to be used are the following (see Table 4-1):

Table 4-1 Table collecting main factors influence the CEM to be used

Factors influence CEM to be used
Level of project definition
Data available (historical, design, etc.)
End use (and costumer expectations)
Resources (people, estimating tools, budget, etc.)
Schedule (time available)

According to the requirement of “how to address the factors that influence the CE selection”, Table 4-2 presents their relevance against the selection of the CEM, the training purposes and the difficulty to quantify them.

Table 4-2 Factors against measurement of relevance

Factors	**Selection CEM**	**Training purposes**	**Difficulty to quantify**
Level of project definition	High	Medium	Medium
Data	High	High	Medium
Schedule	Medium	Low	High
Resources	Medium	High	High
End use	High	Medium	Low

Table 4-3 summarises how these factors have been considered and addressed.

Table 4-3 How factors considered in this research .(*)=Parameter considered

Parameter	**Considerations**	(*)
Level of project definition	It is considered as is the main factor that implicitly defines the characteristics of the cost estimate.	✓
Data	In terms of type, amount when relevant (ex. significant for statistical) and quality (ex. saying: similar project) of data. This issue is considering that you have got the high level requirement in terms of data to start a CEM.	✓
Schedule	Time is not explicitly requested due to the difficulty to define the time required for each of the 3 CEM. However, this idea is indirectly considered in the preparation effort level as one of the level of project stage characteristics. If time wanted to be considered, a deep study trying to map time with complexity of the project should be done. For training purposes: - Not relevant to understand the CE process. - Relevant to know that this issue may influence the selection criteria. Mention it somewhere/somehow in the feedback.	✗
Resources	Budget. Not as an input as a deep study to consider the relation of the budget (establishing some limits) with the CEM to use would require. For training purposes: - Not relevant to understand the CE process. - Relevant to know that this issue may influence the selection criteria. Mention it somewhere/somehow in the feedback.	✗
	Questions address main resources in terms of people and tools required to perform the CE process. This issue is considering that you have got the high level requirement in terms of resources to start a CEM.	✓
End use	The End use is considered (feasibility study, project control, bid, etc.).	✓
	Customer expectation when selecting the CEM is not considered. Sometimes customer requests from you to use a particular CEM or to fill a particular format (like a spreadsheet with all the detailed data requested or saying that wants you use the software Price-H). In both situations the suggestion of the form does not make sense as you know what to do.	✗

4.4.1 Definition of the Form

Inputs on the different factors which characterise the cost estimation and influence the CEM selection (as considered in Table 4-3) are obtained using a form (self-completion questionnaire). The form requests the user to answer some questions. According to them the e-mentor suggests which CEM are suitable (Figure 4-5). This feedback does not expect to impose to the user the CEMs to use; it gives recommendation criteria for the selected CEM which will come from the user's decision.

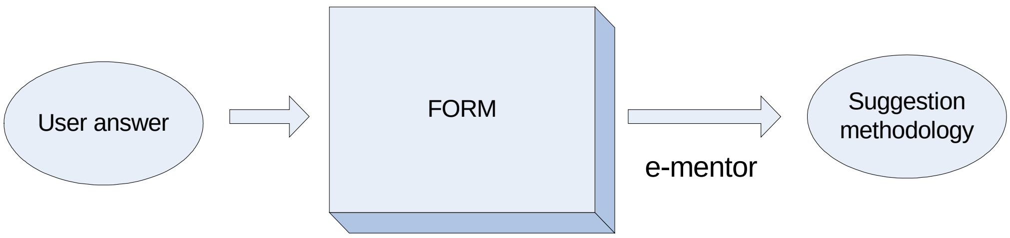


Figure 4-5 High level process description of 'suggestion of the CEM'

Specifications or requirements when defining the form are listed below:

- The three CEMs targeted are: analogy, detailed and parametric.
- Consider the two main reasons of the creation form (suggest the suitable CEM):
    - Suggest the CEM that better suits the characteristics of the project (e.g. level of project definition). The cost estimator as a trainee will get feedback about the selection criteria.
    - Disallow the user to start the CE process without taking into account the main requirements of the CEM, and therefore, face in the middle of the process that they struggled and can not do the cost estimation using that CEM. However, it is not said that during the CE process the cost estimator won't have to stop the process and work on some requirements before having to fill the form from the application. The availability of the data provided from the V-CES database will be considered.

- Factors that influence the CEM selection have been prioritized and considered according to the relevance to:
    - Influence the CEM to use.
    - Training purposes in terms of understanding the reasons you select that CEM and the CE process (with E-mentor).
    - Difficulty to quantify.
- Establish the form in terms of type and amount of questions, and format. The following issues have been considered due to the web-based interface and interaction:
        - The number of questions/requests has to be sensible enough, focus and minimum time consuming to avoid the reduction of the level of response.
        - Questions must be relevant enough to characterise the parameters that define each CEM.
- Establish a rule based system in order to link the users' answers to the suggestion of the CEM feedback. The feedback on the suggestion of the CEM has to contain a training approach. The user, as a trainee point of view, should understand the reasoning under the suggested CEM.

The form to suggest the suitable CEM has been structured in two sections (see Figure 4-6). Section 1 considers the *level of project definition* and, indirectly, the *end usage*. Section 2 is targeting *data* and *resources* required to start the three CEM targeted: analogy, detailed and parametric.

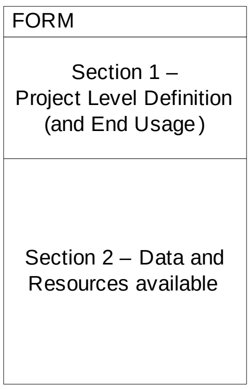


Figure 4-6 Main structure of the form

Section 1 – Level of project definition

From the literature review, many different ways to identify the cost estimate according to the project life cycle were identified.

The approach chosen by this study is the one proposed by the AACE (2004). AACE has defined a 5 estimate classification; for a generic industry as presented in Table 2-2 and for "process industries" in ANNEX E. This has been the starting point of section 1 in this study. The adaptation of the tables has been done due to following reasons (see the process in ANNEX E):

- Definition of 3 classes instead of 5 because of:
    - Balance the number and relevance of questions/options.
    - Other organisations (see literature review) have classified the cost estimate from 3 to 6 classes.
- Three possible CEMs to be selected: analogy, detailed and parametric.
- Accuracies in percentage are just defined for applied engineering; procurement and construction of the "Process Industries".

The final table after being adapted to the thesis requirements and validated with 8 cost estimators is presented in Table 4-4.

Table 4-4 Final table of section 1 of the form

Product/ Project development stage	**Level of project/ product definition (%)**	**Expected accuracy**	**End usage (typical purpose of estimate)**	**Preparation effort level**	**MEC**
☐ Preliminary	<10 %	-30% / 50%	Screening, Conceptual study or Feasibility	(1) Low	Analogy Parametric
☐ Intermediate	10% – 40%	-15% / 30%	Budget, Authorization, or Control	(2) Medium	Analogy Parametric Detailed
☐ Final	>40%	-5% / 15%	Control, Bid/Tender or Check estimate	(3) High	Detailed

Section 2 – Data and Resources available

After a deep understanding of the three CEMs: analogy, detailed and parametric, the author chose from literature review and experience within the V-CES project the main requirements in terms of data and resources needed for each CEM. This was the basis to create the first set of closed questions to evaluate the acquisition of these requirements. Main requirements were validated and a second set of questions to target them was defined (see ANNEX D, version 2).

After the validation process, which is explained in further section 4.4.3, section 2 of the form ended as presented in Table 4-5.

Table 4-5 Final table on section 2 of the form

Checking Data available and main resources	YES	NO	CEM
1 - Do you know which material/s will be used, Bill of Materials?			D
2 - Do you know which labour types will be required?			D
3 - Do you know which equipment type (machines) will be used?			D
4 - Do you have cost data from a similar previous product/project?			A
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).			A
6 - Do you have (statistically) a significant amount of historical cost data related to the previous products/projects?			P
7 - Do you possess software tools or other bespoke packages to perform statistical analysis of the historical cost data?			P
8 -Do you know the process involved in the life cycle of the product/project you intend to estimate?			D

CEM: Cost Estimating Methodology
D: Detailed, A: Analogy, P: Parametric

Then if Detailed Cost Estimating is a suitable methodology a second asking for the material, labour and equipment cost data is shown.

	YES	SOME	NO
1 - Are you able to obtain material cost data? (e.g. price of the material per weight or length, amount of weight or length, rejection rate)			
2 - Are you able to obtain labour cost data? (e.g. salaries, fringes, timing component required)			
3 - Are you able to obtain equipment cost data? (e.g. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time)			

4.4.2 Rules to Suggest the Cost Estimating Methodology

The purpose of the form presented in the previous section is to receive inputs to describe the cost estimating context, in terms of stage within the project lifecycle and data/resources available. Each of the options and questions in the form is targeting one, two or three of the CEMs. In order to provide some feedback to suggest the suitability of the three CEMs: analogy, detailed and parametric, a production rule-based system covers all possible combination of inputs.

Before setting up the specific rules, six main drivers to present feedback were defined to consider when suggesting the CEM:

- Justifies why a CEM is not suitable and what is required in order to make it suitable.
- Recommends to the user to perform many suitable estimates according to the case to cross check and be more confident about the result.
- If a 'detailed' estimate is an option and you are not able to get all labour, machine or material data then data available in the V-CES database will be provided.
- If you are in the Intermediate or Final stage, bear in mind the cost estimation you may have done in previous stages.
- If you have many options, establish some high level criteria for the selection. The criteria will consider factors like: time to do it and accuracy required.

Following, the algorithmic code is partially presented (after Table 4-7), together with the variables involved and some of the general comments seen along the coding (see Table 4-6 and Table 4-7).

Table 4-6 Coding variables to suggest the CEM (inputs on the form)

Variable Name	Variable Type	Meaning
Q1	Boolean	1 - Do you know which material/s will be used, Bill of Materials?
Q2	Boolean	2 - Do you know which labour types will be required?
Q3	Boolean	3 - Do you know which equipment type (machines) will be used?
Q4	Boolean	4 - Do you have cost data from a similar previous product/project?
Q5	Boolean	5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).
Q6	Boolean	6 - Do you have (statistically) a significant amount of historical cost data related to the previous products/projects?
Q7	Boolean	7 - Do you possess software tools or other bespoke packages to perform statistical analysis of the historical cost data?
Q8	Boolean	8 -Do you know the process involved in the life cycle of the product/project you intend to estimate?
QD1	3 values	1 - Are you able to obtain material cost data? (e.g. price of the material per weight or length, amount of weight or length, rejection rate)
QD2	3 values	2 - Are you able to obtain labour cost data? (e.g. salaries, fringes, timing component required)
QD3	3 values	3 - Are you able to obtain equipment cost data? (e.g. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time)
preliminary	Boolean	Preliminary stage within the project life cycle
Intermediate	Boolean	Intermediate stage within the project life cycle
final	Boolean	Final stage within the project life cycle
A	Boolean	Analogy suitability
P	Boolean	Parametric suitability
D1	Boolean	Detailed suitability but not all data or resources are available
D	Boolean	Detailed suitability and all data and resources are available

* Boolean= yes/no - 3 values=yes/no/some

Table 4-7 Generic comments used within the coding to suggest the CEM

Variable	Comment
Comment_A1	"You should look for the data or identify someone to support the rational similarities and differences between projects/products before starting an Analogy Cost Estimate".
Comment_A	"You should first identify a similar previous product/project and then look for its cost data. If you can not do this, then the Analogy Methodology is not suitable".
Comment_P1	"You need a tool to develop a statistical analysis; if you do not have this you should not start the Parametric Methodology".
Comment_P	"You should first identify a significant amount of historical data related to previous products/projects. If you can not do this, Parametric Methodology is not suitable".
Comment_D	"If you do not know the materials, labour and equipment involved, or the process involved in the life cycle of the product/project, you can not go for the Detailed Methodology".

___Suitability CEM according to questions (part 2 of the form)___________________________

```
If (Q4=yes) then
        If (Q5=yes) then
        A=yes
        Else If (Q5=no) then
        Print Comment_A1
        End if
Else If (Q4=no) then
Print Comment_A
End if

If (Q6=yes) then
        If (7=yes) then
        P=yes
        Else If (Q7=no) then
        Print Comment_P1
        End if
Else If (Q6=no) then
Print Comment_P
End if

If (Q1=Q2=Q3=Q8=yes) then
        D1=yes
        else
        D1=no
        Print Comment_D
End if
```

___Suitability CEM according to questions (part 2 of the form) and project stage____________

If (preliminary=yes) then

If (D1=yes) then
Print "You are probably **not** on the ***Preliminary Stage*** as you should not have a clear picture about materials, labour, equipment and the manufacturing project life cycle. Could you please reconsider the project level definition or redefine questions 1, 2, 3 and 8?"

Else If (A=yes and P=yes) then
Print "You can use **both Analogy and Parametric Methodologies**. E-mentor suggests you create two cost estimates using both methodologies. This will allow you to check the results and be more confident about the outcome.

If time is a constraint and you have to select just one methodology your decision should bear in mind:

- Targeting the accuracy to achieve (quality of data and resources):
    - The **similarity** with the **previous project/product** is really strong, better than the relevance with the historical data available, then **Analogy** Methodology.
    - The relevance of the **historical data** available is better than the similarity with the previous project/product, then **Parametric** Methodology.
- If you have the required data/resources the Analogy Methodology will probably take less time than the Parametric Methodology".

Else If (A=no and P=yes) then
According to your current availability of data, resources and project phase you should carry on the **Parametric Methodology**.

The Analogy Methodology is not suitable for the reason: *Comment_A*
If you have the time and you can achieve the requirements missing for the Analogy Methodology, E-mentor suggests you to do the estimate using both methodologies to verify and be more confident of the result.

Else If (A=yes and P=no) then
According to your current availability of data, resources and project phase you should carry out the **Analogy Methodology**.

The parametric is not suitable for the reason: *Comment_P*
If you have the time and you can achieve the requirements missing for the Parametric Methodology, E-mentor suggests you to do the estimate using both methodologies to verify and be more confident of the result.

Else If (A=no and P=no) then
You do **not** fulfil any of the **minimum requirements** needed to start the CE process using either the Analogy or Parametric Methodologies.
The requirement to start the Analogy is:
- *Comment_A*
The requirement to start the Parametric is:
- *Comment_P*

End if
End if

ElseIf (intermediate=yes) then

See code in ANNEX F

ElseIf (final=yes) then

See code in ANNEX F

End if

Each of the project life cycle stages (part 1 in form, see Table 4-4) and the questions (part 2 in the form, see Table 4-5) of the form are linked with the CEM after being validated with CE experts. Thanks to this match and applying the criteria presented at the beginning of section 4.2.2, the author defined different feedbacks for all possible combinations of inputs. The feedback was then validated and the results of this validation will be presented in chapter 5.

The validation of the algorithm was done once the framework was implemented due to the difficulty and time consumption in testing the rules in paper format. Otherwise, it would have required a big exercise of conceptual interpretation.

4.4.3 Validation

Validation process is depicted in Figure 4-7 and explained as following.

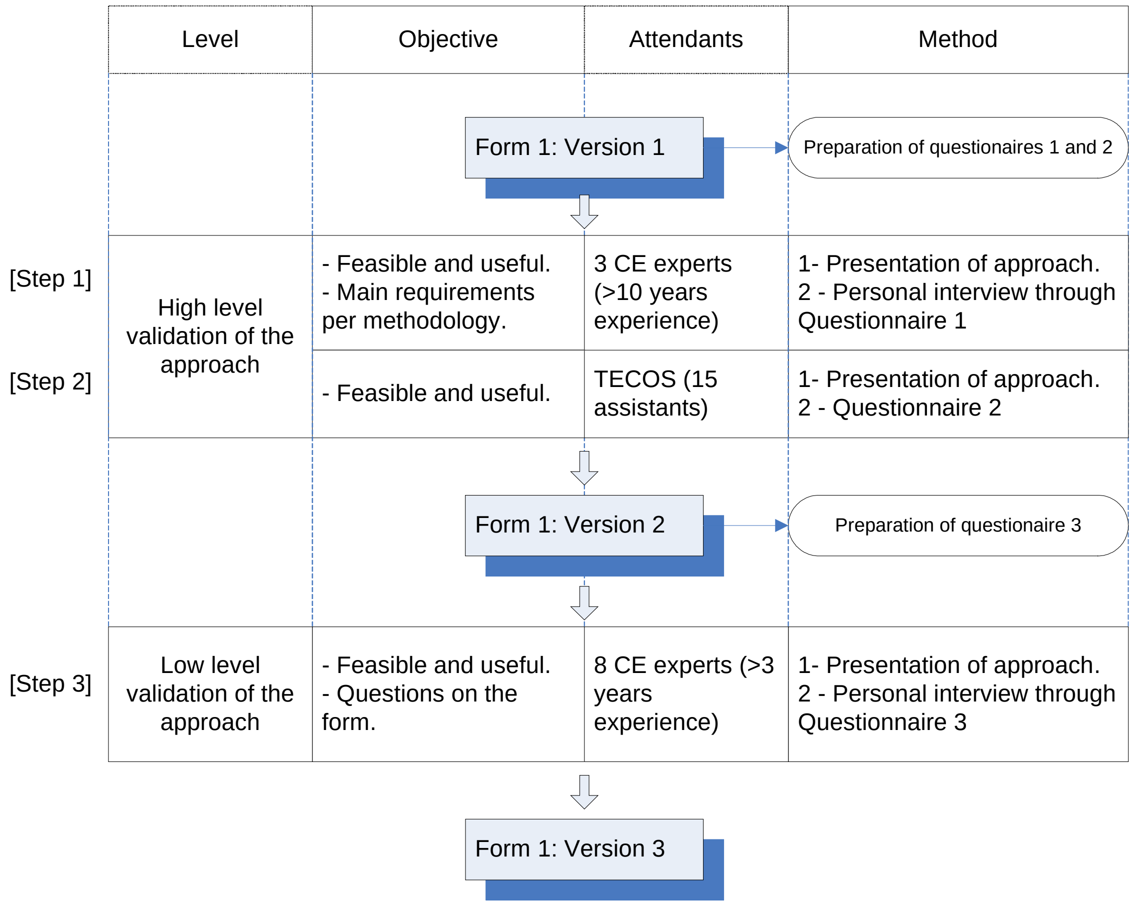


Figure 4-7 Summary of the validation of the framework

The definition of the form 1 (version 1) was completed by the author after adapting the table of the project life cycle stages defined by AACE (2004) and defining the first set of questions from the understanding of the main requirements from the CEM (as explained in section 4.4.1).

The questionnaires to validate the form with cost estimators were mainly based in the exercise of thinking of real examples they had to estimate. The criteria of doing the exercise like this instead of suggesting a project/product (ex. estimation of a bicycle) common for all the interviewed was the following:

- The outcome depends more on the characteristics of the situation in terms of when did it happen and what were the data and resources available more than the skills and ability of the cost estimator.
- Identify which was the situation in terms of stage of the project lifecycle, data and resources available, instead of trying to imagine what would happen.
- Be able to check if the CEMs they used in the real situation agree with those suggested by the e-mentor.

Closed questions were firstly targeted to make the results easier to compare, but some additional open questions were required to justify the closed answers as a main approach presented in chapter 3.

[Step 1]: High level validation of the approach

- **Objective:**
    - High level validation of the framework from experts. To have a first view from experts (in the 3 CEMs) about the approach taken and the questions in terms of targeting the major requirements per each CEM.
        - Validation of the approach and the framework, in terms of correct and useful approach. (Approach: “A form will ask questions about project life cycle, data and resources available. According to the user answers, the e-mentor will suggest the suitability of the 3 CEMs targeted”).
        - Validation of content: Main requirements to carry out each of the 3 CEMs in terms of data and resources and the questions to address them are considered.

- **Attendants:**
  - Experts: Users 1, 2 and 5 (see Table 3-1).
    Selection criteria: cost estimators with more than 10 years of experience in manufacturing.
- **Method:**
  - Presentation of the framework through a power point presentation for 10 minutes.
  - Give them a questionnaire (questionnaire 1, Annex B) to go through by interviewing them. There are 4 questions, 3 are closed and 1 opened.
- **Outcome:**
  - New set of main requirements.
  - Redefinition of the form (version 1 annex D): version 2

Table 4-8 summarises the answers extracted.

Table 4-8 Answers from questionnaire 1 (see Annex B)

	Type of project/ product	1- Complete form	2- Relevance questions	3- Modify form. Change?	4- Like form
User 1	Composite Fan Cowl Doors	Yes	Yes	**Yes** - For a detailed a structured BOM is required. - Before asking for material, equipment and labour cost data is needed to ask if they know which material, equipment and labour types will be used. In early stages (when you will use analogy or parametric) perhaps you still do not know the exact material. (*)	Yes
User 2	Classified/ Commercial	Yes	Yes	**No** - He thinks this is a good level of detail; more questions are likely to reduce the level of response. - Agreement on (*)	Yes
User 5	Nacelle	No	No (Not particularly)	**Yes** - BOM is required for detailed. - Agreement on (*)	Yes

After the meeting, an important issue was point out, what implied to redefine section 2 of the form before starting a second validation of the form:
- For the detailed CEM, before asking for the material, labour and equipment cost data, it is necessary to ask if you know about the material, labour type and equipment type that will be used, as in early stages you usually do not have this information.

Therefore, main requirements for the three CEMs were redefined as presented in Table 4-9. Three first requirements for detailed methodology (see in bold Table 4-9) were added to the original table.

Table 4-9 Main requirements for each of the CEM

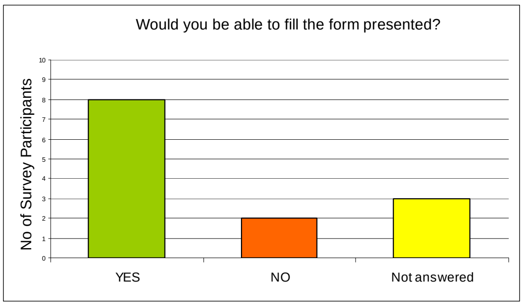
Analogy	Detailed	Parametric
- Cost data from a similar project/product - Capability to identify similarities and differences between new and previous project (cost factors).	**- Material will be used.** **- Labour type will be used.** **- Equipment type will be used.** - Material cost data. - Equipment cost data. - Labour cost data - Knowledge about the manufacturing process	- Historical data - Statistical analysis of data

[Step 2]: High level validation of the approach

- **Objective:** Validation of the framework in terms of being a correct and useful approach.
- **Attendant:** TECOS Seminar: 13 participants.
- **Method:** Presentation of the framework through a power point presentation for 10 minutes. Give them a questionnaire (questionnaire 2, Anne B) which will be self answered (not individual support trough the answers). Meanwhile author was presenting the framework attendants were requested to fill questionnaires.
- **Outcome:** Acceptance of the approach. Appreciation of this service from professionals.

Feedback from TECOS

The results were the following:



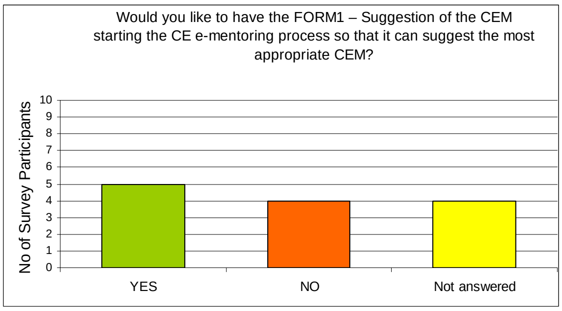


Figure 4-8 Feedback from TECOS

The novice option view was directly considered as more than half of the participants had less than 3 years of experience in CE (see ANNEX A).

At that moment the system was not implemented. It was difficult for them to visualise and put into context the output of the service: get a suggested CEM and therefore understand the usefulness of it. This could be the reason why 5 attendants saw the usefulness, 4 did not and 4 did not answer to that question (right graph in Figure 4-8).

[Step 3]: Low level validation of the approach

- **Objective:**
    - o Validation of the framework from CE experts.
    - o Review questions to make sure they characterise the 3 CEMs and they are understandable.
    - o Validation of accuracies per each stage of the project life cycle.
- **Attendants:**
    - o Experts: Users 1, 2, 3, 4, 5, 6, 7 and 8 (see Table 3-1).
      Selection criteria: cost estimators with more than 3 years of experience in manufacturing. Considering the years of experience, they could be considered as experts but it does not mean they are experts for the 3 CEMs. When answering the usefulness, they were thinking of novices who start implementing competences as

a cost estimator or by themselves as they can be considered experts in one CEM and a novice in another.

- **Method:**
  - o Presentation of the framework through a power point presentation for 10 minutes.
  - o Give them a questionnaire (questionnaire 3, Annex B) to go trough by interviewing them. There are 4 questions, 3 are closed and 1 opened.
- **Outcome:**
  - o Redefinition of the form (version 2, Annex D): version 3

After the first revision of the form (from version 1 to version 2, annex D), author proceeded to validate the form with 8 experts, following the same interviewed process (see Figure 4-7) done in step 1 validation: See feedback in Table 4-10.

Table 4-10 Validation framework of 'suggestion of the CEM'

	Type of project/ product	1- Complete form	2- Relevance questions	3- Modify form. Change?	4- Like form
User 1	Composite Fan Cowl Doors	Yes	Yes	**No**	Yes
User 2	Classified/ Commercial	Yes	Yes	**No** - This is a good level of detailed; more questions are likely to reduce the level of response.	Yes
User 3	2 door convertible	Yes	Yes	In real work there would be financial and time constraints.	Yes
User 4	Radomes	Yes	Yes	**Yes** - Is the cost data reliable?	Yes
User 5	Nacelle	No	No (Not particularly)	**No**	Yes
User 6	Steering Wheel	Yes	Yes	**Yes** - Time could be considered according to the complexity of the project/product.	Yes
User 7	Escape Plus (gas treatment machine)	Yes	Yes	**No**	Yes
User 8	Estimating drilling process	Yes	Yes	**No**	Yes

Following was concluded after the comments received from the attendants:

- Time would not be considered as an input as explained in Table 4-3, although the feedback would consider this issue in a qualitative way.
- Some as an answer option would be added in table 3 of form 1 to help the user feeling better understood/represented in the answer, but it would not be added in table 2. The fact of answering some in table 2 would cause 2 major problems:
    - o People tend to answer some 'as a safer answer'.
    - o Questions of some only make sense if the service required can be fully or partially provided, as it is the case of detailed data. If the answer is NO the user has to look for it, the e-mentor will not provide what is missing.
- The reliability of the cost data affects the accuracy but it would not be considered as major requirement to address as a question.

Table 4-11 presents the evolution of the questions after the validating process with the experts. Version 1 is the initial and version 3 is the final.

Table 4-11 Evolution of the section 2 of the form

Questions in version 1	Questions in version 3
Q1 - Do you have material cost data? (ex. price material per weight or length, amount of weight or length, rejection rate)	Q1 – Do you know which material/s will be used, Bill of Materials?
Q2 - Do you have labour cost data? (ex. salaries, fringes, timing component required)	Q2 - Do you know which labour types will be required?
Q3 - Do you have equipment cost data? (ex. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time…)	Q3 - Do you know which equipment type (machines) will be used?
Q4 - Do you have cost data from a similar previous product/project?	Q4 - Do you have cost data from a similar previous product/project?
Q5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology)?	Q5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology)?
Q6 - Do you have statistically significant amount of historical cost data related to previous products/projects?	Q6 - Do you have (statistically) a significant amount of historical cost data related to the previous products/projects?

Q7 - Do you have a way (ex. software tool) to do a statistical analysis of the historical cost data?	Q7 - Do you possess software tools or other bespoke packages to perform statistical analysis of the historical cost data?
Q8 -Do you know the process involved in the life cycle of the product/project you want to estimate?	Q8 -Do you know the process involved in the life cycle of the product/project you intend to estimate?

	QD1 – Are you able to obtain material cost data? (e.g. price of the material per weight or length, amount of weight or length, rejection rate)
	QD2 - Are you able to obtain labour cost data? (e.g. salaries, fringes, timing component required)
	QD3 - Are you able to obtain equipment cost data? (e.g. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time)

Questionnaire 3 in Annex B involved the validation of section 1 from the form. Apart from that, experts were required to define the range of accuracy per each stage of the project life cycle: preliminary, intermediate and final (for sectors aerospace, automotive or semiconductor equipment).

Results are presented in Table 4-12.

Table 4-12 Accuracies for the 3 stages of the project life cycle

Expert	**Main sector (*)**	**Expected accuracy**		
		Preliminary	**Intermediate**	**Final**
User 1	Aerospace	-25%/+25%	-15%/+15%	-5%/+5%
User 2 (High and low level, it depends on the technology)	Aerospace	+/- 40% +/- 100%	+/- 10% +/-50%	+/- 5% +/- 20%
User 3	Automotive	-30%/+40%	-20%/+20%	-10%/+10%
User 4	Aerospace	-30%/+30%	+/- (15-20)%	-10%/+10%
User 5	Aerospace	-40%/+40%	-20%/+20%	-10%/+10%
User 6	Automotive	-30%/+40%	-15%/+25%	-30%/+10%
User 7 (he agreed with the proposed)	Semi-conductor equipment	-30% / +50%	-15% / +30%	-5% / +15%

(*) from the main 3 sectors target by the project framework: aerospace, automotive and semi-conductor equipment.

From the results obtained in Table 4-12, there was difficulty agreeing on a range of numerical values for each of the 3 project lifecycle stages due to the variability of answers; variability of answers were even seen from participants from the same sector and company. However, this test was useful to validate the approach considered by ANSI Standard z94.0 and by Creese and Moore (1990).

Expected accuracies used in the final form are presented in Table 4-13.

Table 4-13 Accuracies selected for the final form

Product/Project development stage	**Expected accuracy**
☐ Preliminary	-30% / +50%
☐ Intermediate	-15% / +30%
☐ Final	-5% / +15%

4.5 Suggestion of the E-training Path

The following section presents the second area where intelligence has been applied (intelligence 2 in Figure 4-4). The e-mentor suggests the e-training path. The e-training path is a recommendation of what the user should do in order to improve their competences. At this stage the research defines the e-training path as the e-courses available on the web that matches with the user interests. Future work could be complemented by suggesting other sources or ways to enhance the professional profile.

As seen in Figure 4-9 first step targets the assessment of the trainee competences. The assessment focuses in two areas:

- Trainee current level on the competences.
- Competences trainee is targeting.

By comparing trainee current and target level on the competences, the system calculates the trainee interests. Out of this evaluation the available e-training courses are suggested as possible ways of achieving their interests.

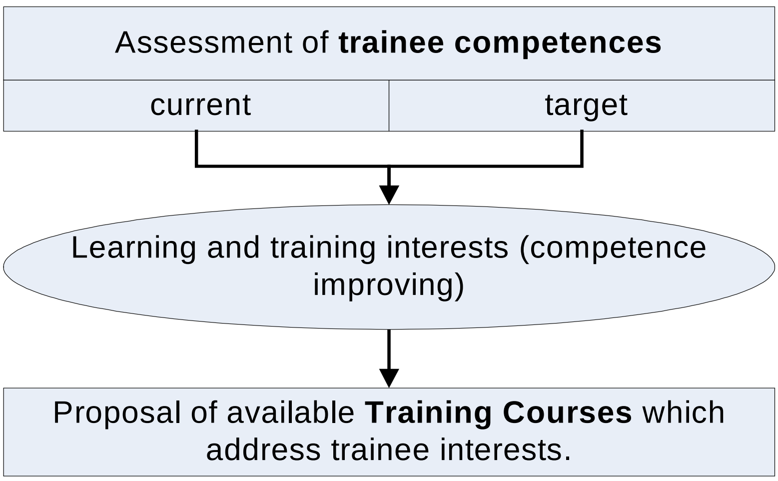


Figure 4-9 E-training path framework

4.5.1 Competence-Based Approach

The assessment of the trainee competences focuses on knowledge and skills, without directly addressing attitude. The attitude issue has not been directly addressed in this research for two main reasons:

- It involves pedagogical needs that are out of the scope.
- Difficulty to address it because of the online channel of communication.

From now on the term competence used in this thesis will consider knowledge and skills, but no attitude.

Knowledge is categorised with three elements (Blanchard and Tracker, 2004):

- Declarative: "*The information we acquire and place into memory*".
- Procedural: "*Understanding of how and when to apply the declarative knowledge*".
- Strategic: "*Awareness of the procedural and declarative knowledge, how it was learned and how can be applied to achieve a specific goal*".

Being *skills* (Blanchard and Tracker, 2004):
"the capacities needed to perform a set of competences that are developed as a result of training and experience. Skills are dependant on knowledge in the sense that the person must know "what" to do and "when" to do it. However, a gap separates knowing those things from actually being able to "do" them."

Figure 4-10 Competence in this thesis: Knowledge and Skills

Blanchard's and Tracker's (2004) definitions are seen in the same philosophy as the V-CES definition. This thesis will use the definitions proposed by V-CES (V-CES Consortium D1.5, 2005):

- **Skill**: "the knowledge and ability that enables a person to carry out an activity properly".
- **Knowledge**: "information and understanding about a subject that a person has".

The sub-classification of knowledge proposed by Blanchard and Tracker (2004) has been used when analysing the training techniques to improve knowledge and skills. Tacit knowledge has not been addressed by this research.

The purposes of separating knowledge from skills are the following:

1- Having the understanding of a competence does not mean you are able to undertake/perform it. An example is when you are reading the solution of an exercise and you understand the solving methodology. If later on you are requested to do a similar exercise without the solution, the fact that you understood the previous one does not imply you will be able to do it. A gap between knowledge and skills is visible.

2- The way to acquire knowledge and skills imply different learning/training methods.

4.5.2 Learning/Training Methods

It has been necessary to establish the useful methods and techniques to acquire knowledge and skills. The range of methods was filtrated and adapted because of the characteristics of the channel of communication: web-based.

- Learning: "the process of gaining knowledge through studying" (V-CES Consortium D1.5, 2005).

- Training: “a systematic process focused on the acquisition of KSAs needed to perform a particular job effectively” (Blanchard and Tracker, 2004).

In the research context (V-CES) and this thesis, training is seen as: “*the process of gaining the knowledge and the skills needed for developing cost estimates*” (V-CES Consortium D2.4, 2005).

Figure 4-11 depicts the main linkage between knowledge/skills and the learning/training methods. The acquisition of skills requires an active performance of a job or activity. The acquisition of knowledge does not require the performance of any job; it can be achieved by studying or lecturing.

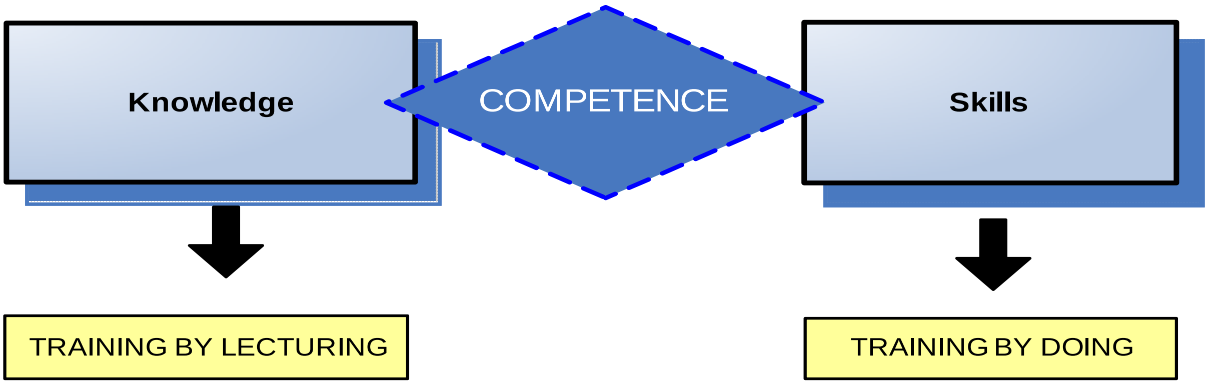


Figure 4-11 Knowledge is targeted by lecturing and skills by doing

The relevant training methods and how this research have addressed them are presented in Table 4-14 (see extended version on table ANNEX J)

Table 4-14 Relevant training methods proposed by Blanchard and Tracker (2004) and adapted to study requirements

<table>
<tr><th>Training Method</th><th>Explanation</th><th>Online application (Moodle)</th><th>Learning Objective (KS)</th></tr>
<tr><td>Lecture</td><td>Presentation of information, it can be printed or oral. Is best used to create understanding of a topic or to influence attitude. “Telling someone about something”.</td><td>Context: “the user has to go through the material but doesn’t have to react after reading it”.
Application:
- Reading documents (information)
- Power point lectures (with or without voice)
- Glossary of terms.
- Reading of an existing case study</td><td>- Declarative knowledge</td></tr>
<tr><td>Discussion method</td><td>Presentation of a topic and then establish an interaction among trainees or between trainer and trainee. The added communication gives it much greater power than lectures.
Two-way flow communication, the trainees’ active implication requires thinking about the content.</td><td>Context: “Discussion and questioning are beneficial because they enhance understanding”.
Application:
- Discussion in a chat.
- Asynchronous contact by mailing.
- Questions about the content of the lecture.
- Quizzes about the content of the lecture.</td><td>- Declarative knowledge.
- Procedural knowledge.</td></tr>
<tr><td rowspan="5">Simulation/Games</td><td colspan="3">The section simulation/Games is going to be understood like exercises/assignments in which the trainee has to develop competences related with the topic.
Examples: (1) Do a statistical analysis with historical data provided and then the trainer will be corrected by a mentor.
(2) Carry out a cost estimation using the e-mentor and submitted to the trainer.
(3) Questions like: “What would you do after normalising the data?” (asking for the process)</td></tr>
<tr><td>Equipment simulators: mechanical devises that require trainees to use the same procedures, movement, or decision processes they would use with equipment back on the job.</td><td>As the purpose is to work with equipment, this kind of exercise could be using the e-mentor as a tool.</td><td>- Procedural knowledge and skills.</td></tr>
<tr><td rowspan="3">Case studies: trainee is usually presented with a story (written or videotaped), key elements, and problems of a real of imaginary organisation. There are usually some questions at the end of the case. Trainee must take certain judgments and identify possible solutions to the problem.</td><td colspan="2">2 different approaches with cases studies can be done:</td></tr>
<tr><td>- Propose a case study as an assignment to be delivered and corrected for the mentor.</td><td>- Declarative and strategic knowledge. [it focus more on the “what to do” than on “how to get it done”].</td></tr>
<tr><td>- Take a case study as a best practise to go thought the e-mentor.</td><td>- Skills. [The use of the case study is like an equipment simulation without feedback].</td></tr>
</table>

As a summary, the acquisition of knowledge will be completed by lecturing activities and the acquisition of skills by doing activities as shown in Figure 4-12.

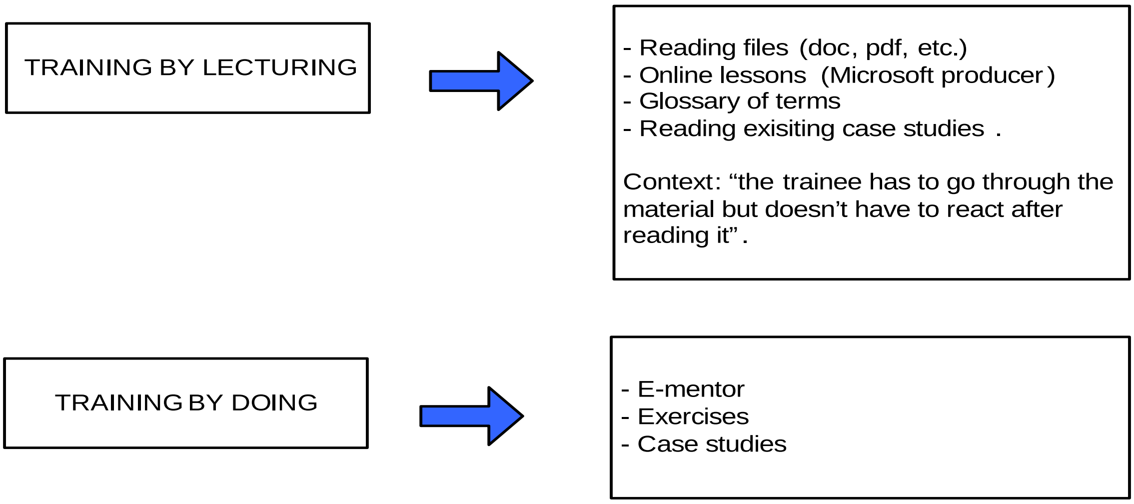


Figure 4-12 Possible activities for training by lecturing and by doing

4.5.3 Assessment Approach

The key driver of the assessment approach has been the differentiation of knowledge and skills. Previous sub-sections have defined the concepts of knowledge, skills and competences and propose different suitable training methods. The assessment of the level of competences and the suggestion of the e-training path reflects and designs a framework considering these issues.

The assessment implies:

1- Definition of the set of knowledge and skills for each of the competences required.

   This approach has been considered by the Government of commerce for management competences as presented in the literature review (see Table 2-8).

2- The grading system to assess the level is based on the differentiation of knowledge and skills.

The purpose of the assessment is to get the current and target level for each of the competences required. According to these parameters the e-mentor can suggest the e-training path.

To obtain the current and target level of the competence, the following approach has been defined (see Figure 4-13):

Current level

Assessment of the level of the competence:

1- System-assessment:
   a. Assess set of skills (Select which you have and which not)
   b. Assess set of knowledge.
      i. Select which you have and which not
      ii. Carry out a knowledge test

2- Manual assessment.

The author believes that going through the complete system assessment, path 1.b.ii, is the best way to assess the level of a particular competence; a more objective result can be achieved. The limitation is that the system is more time consuming. Therefore, the competences which the trainee is really sure about the level or is not especially interested in can be manually assessed (2). For the same reason the test of knowledge is not compulsory, but strongly recommended to assess the knowledge on the competence.

Target level

The system requests this parameter to be entered manually, assuming that the user is aware of which competences wants to improve. However, future research could be done in this area trying to recommend to the trainee which competences should improve to become an expert in a particular CEM.

The assessment is completed when the trainee gets the suggestion of the e-training path. When the assessment should be done again or automatically updated according to the trainee evolution is not considered by this thesis.

Competences Cost Estimator

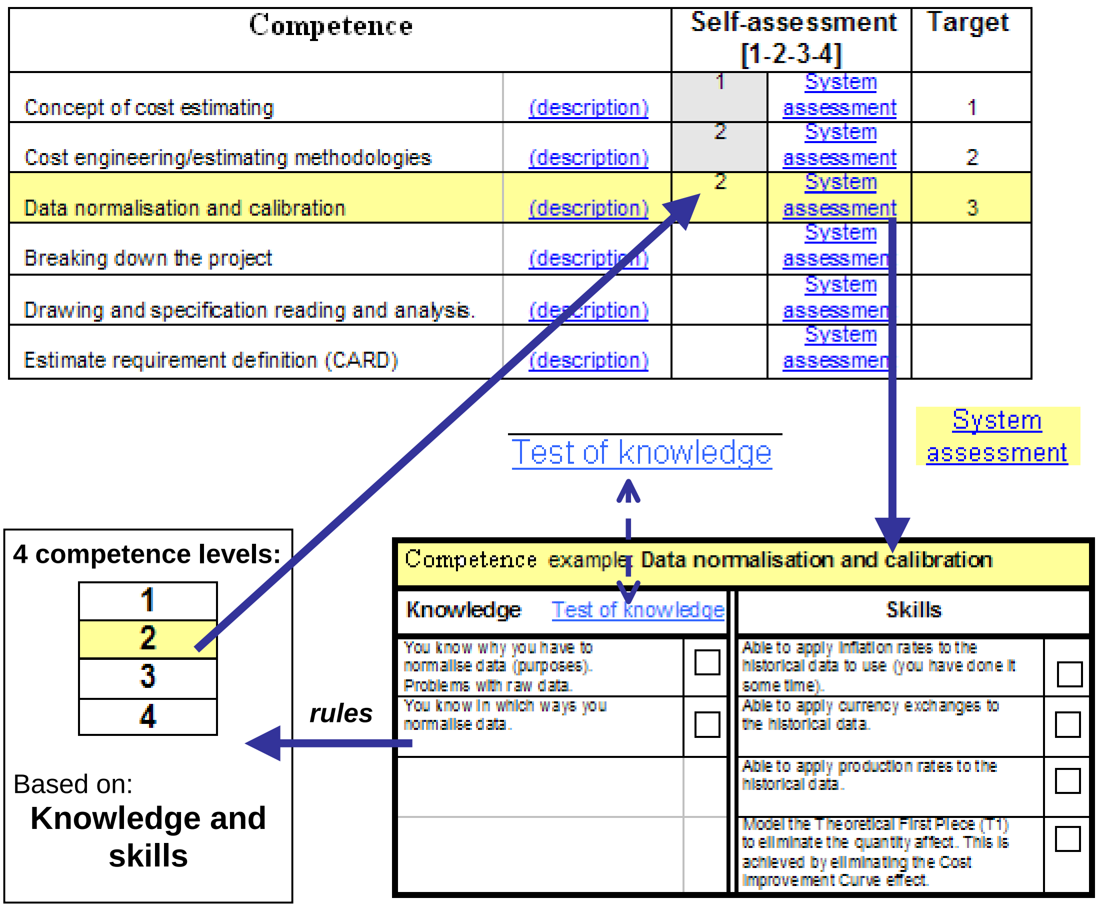


Figure 4-13 Assessment of a competence

Level of competences

Per each competence there are 4 possible levels based on the acquisition of knowledge and skills (see Table 4-15 and Table 4-16). Experience and certification have not been directly considered as an input when grading the level of competence.

Table 4-15 Classification level for the mentor or teacher

Level	Description	How is it addressed
1	< 50 % of K	Main Purpose: *Declarative Knowledge*. The basic content of the competence is addressed by: - **Lectures** material. - **Discussion** methods.
2	50 < % of K < 90	Main Purpose: *Procedural Knowledge* and *low level skills*. The basic content of the competence is addressed by: - **Low level exercises/assignments** (simulation/games).
3	> 90 % of K And < 50 % S	Main Purpose: *High level skills*. The basic content of the competence is addressed by: **- High level exercises/assignments** (simulation/games).
4	> 90 % of K And > 50 % S	Training will not be provided for this level.

K= Set of knowledge per competence / S= set of skills per competence
Assumptions: - "To acquire skills you have to previously acquire the knowledge if it is missing".
- "Having level n assumes that you possess levels: (n-1), (n-2), …, and 1".

If the user is expected to answer without using the system assessment, a qualitative description added to the percentage of knowledge and skills was required as shown in Table 4-16.

Table 4-16 Classification level for the trainee

Level	Description
1	You have **little** understanding of the **knowledge** the competence requires (you possess less than 50% of the knowledge required). (< 50 % of K)
2	You have a quite good understanding of the **knowledge** the competence requires (you possess between 50% and 90% of the knowledge required). (50 < % of K < 90)
3	You have a really good understanding of the **knowledge** (more than 90%) but not many **skills** (less than 50%) the competence requires. (> 90 % of K And < 50 % S)
4	You have a really good understanding of the **knowledge** (more than 90% of the knowledge required) and good **skills** (more than 50% of the skills required) the competence requires. (> 90 % of K And > 50 % S)

Knowledge (K): "information and understanding about a subject that a person has" [V-CES]. I understand it but I do not necessary know how to do it.

Skill (S): "is the knowledge and ability that enables a person to carry out an activity correctly. ' What to do and when'" [V-CES]. I know how to do it after having done it several times.

Suggestion of the e-course

The suggestion of the e-training courses is based on the self-assessment and the target level of competences.

Each course targets a specific set of competences at specific levels. A gap between the current and target level of the competence shows an interest of improving the capabilities on that competence. The system counts how many times each of the courses has been targeted in this way. A gap between the current and target level targets a course when the grade addressed by the course is bigger than the current level on the competence and inferior or equal to the target level. For example, if course x is addressing competence y with level 2 and 3, and the trainee has a current level on competence y of 1 and want to improve till 2, counter of course x will value 1. If trainee wanted to improve till level 3 or 4, then counter of course x will value 2. Courses are listed from the course with biggest counter to the least.

Following is presented the high level algorithm to show the functionality of the programming code.

```
$count=0;
If (assessment requested) then
{
        For ($i=1; $i<$count; $i++)
        {
        $competence_id= competence i;
        $self_level= read current level of competence i;
        $target_level= read target level from competence i;
```

```
        ////////////////////////////// Select courses targeted by competence i //////////////////////////////
        Select ($course_id,level) from (tm_competence) where
        (competence_id=$competence_id)
                While ($course_id)
                {
                        If (level>$self_level) And (level<=$target_level) then
                        {
                        $Course_id_counter= $Course_id_counter+1;
                        }
                }
        }
        ////////////////////////////// Listing the courses available that suits the trainee interests////////
        Show courses titles from the biggest to the smallest $Course_id_counter
}
```

4.5.4 Validation

The framework has to be validated to show the relevance to differentiate knowledge from skills, the proposal of a knowledge test and how the user would feel by being assessed using a web-based environment. Three questions were defined and then compounded in questionnaire 5 from ANNEX B. Each one target one of the requirements desired to validate as shown in Table 4-17.

Table 4-17 Requirements targeted by the following three questions

Question	Target
1	Validation of the **approach**: knowledge and skills.
2	Validation of the **approach**: having a test to do.
3	Validation of the **approach**: usefulness.

The three questions are presented as following:

1- Is the differentiation between knowledge and skills relevant to you?
☐ Yes ☐ No

2- Would you like to be able to test your knowledge when you are not sure about the knowledge you have in a particular competence?
☐ Yes ☐ No

3- Would you feel comfortable in going through this assessment using a software based environment? ☐ Yes ☐ No

Results from 13 interviewed people from TECOS (Figure 4-14) and 9 cost estimators (Table 4-18, see profile in Table 3-1) are presented below (see the profile of attendees in ANNEX A):

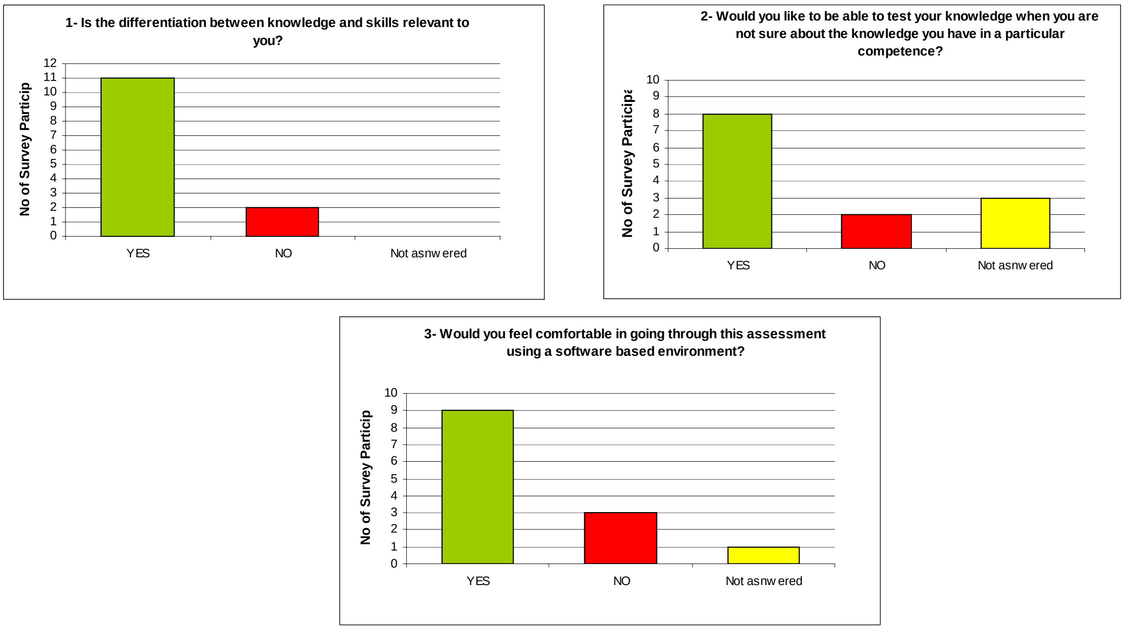


Figure 4-14 Results from TECOS

Table 4-18 Results from individual interviewed cost estimators

	1 – Relevance differentiation K&S	2- Test of knowledge	3- Validity/comfort assessment
User 1	Yes	Yes	Yes
User 2	Yes	Yes	Yes
User 3	Yes	Yes	Yes
User 4	Yes	Yes	Yes
User 5	Yes	Yes	Yes
User 10	Yes	Yes	Yes
User 12	Yes	Yes	Yes
User 13	Yes	Yes	Yes
User 14	Yes	Yes	Yes

Results show the validity of the approach in terms of differentiating knowledge from skills, assessing the knowledge through a test and the user of a software based environment to carry out the assessment.

The validation process in TECOS was done globally. After explaining the approach, questionnaires were distributed among the audience. This explains why some of the questions were not answered. A second validation process was done individually with other interviewees (see profile in Table 3-1); better and personal explanations were provided to the interviewees. Table 4-18 shows their answers. Agreement with the main drivers of the approach: knowledge, skills and test of knowledge is seen.

In order to validate the grading system based in knowledge and skills, the way to list the courses and the capacity to match the courses with the competences, questionnaire 5a (see ANNEX B) was delivered within individual interviews with users 1, 2, 3, 13 and 14 (see Table 3-1). The targeted interviewed people at that point were experts with a relationship with academia. Results are presented in Table 4-19.

Table 4-19 Results from interviewed experts with academia relation

	1 – Level of competence based on K&S	2- Listing courses				3- As a teacher be able to grade the course.
		a.	b.	c.	d.	
User 1	Yes	Yes	Yes	Yes	Yes	Yes
User 2	Yes	Yes	Yes	Yes	Yes	Not sure
User 3	Yes	Yes	Yes	Yes	Yes	Yes
User 13	Yes. Somebody may have all the knowledge with no skills	Yes	Yes	Yes. Really liked prioritisation	Yes	Yes
User 14	Yes. Somebody may have all the knowledge with no skills	Yes	Yes	Yes. Really liked prioritisation	Yes	Yes

4.6 Trainee as Novice or Expert

The approach taken by the research to define the trainee as a novice or expert is based on the competence grading system (see Figure 4-15). The trainee obtains level from 1 to 4 per each competence using the system described in section 4.4.

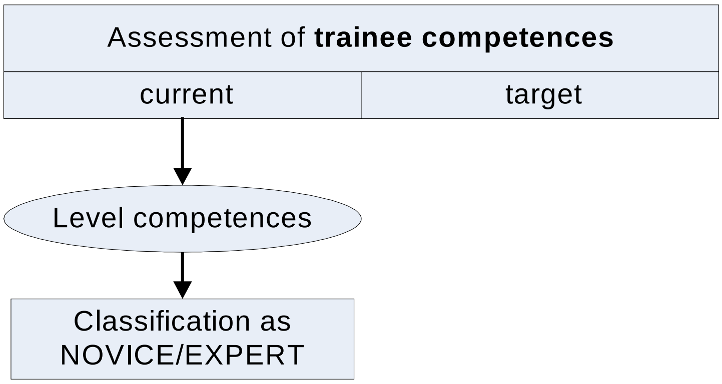


Figure 4-15 Top level view on the approach novice/expert

The approach of novice and expert has been done in 2 different levels:
[Level 1] The trainee is considered as a novice or expert per each competence.
[Level 2] The trainee is considered as novice or expert per each of the three CEMs addressed in this study: Analogy, Detailed and Parametric.

The low level of definition (level 1) considers the trainee as a novice if it has either level 1 or 2 in that competence and expert having either level 3 or 4. Figure 4-16 deploys it, differentiating 2 levels in novice (novice 1 and novice 2) and 2 levels for expert (expert 1 and expert 2).

As the competences are closely related with steps on the CE process, this allows and leads to implement help tailored to trainee needs further presented in section 4.6.

Level of competence	Expertise
1	Novice 1
2	Novice 2
3	Expert 1
4	Expert 2

“I’m novice or expert according to the competence I’m talking about”

Figure 4-16 Relation between level of competence and novice/expert

From the novice/expert consideration per each competence, it is possible to define if the trainee is a novice or expert when carrying out cost estimates with the three CEMs. Each of the CEM is a cluster formed by the competences linked with the CEM.

The consideration of novice and expert at the methodology level make sense for mainly 2 reasons:

- Cost estimators with more than 10 years of experience in the Cost Estimating area may be expert in one CEM and novice in another CEM.
- Some actions can be decided when presenting the e-mentor tool proposed by the research context (CE process), such as presenting the information in different screens, display more or less information.

The method to decide if the trainee is novice or expert for the three CEMs (analogy, detailed and parametric) follows this first criterion:
“To be considered as an expert for methodology x (being x analogy, detailed or parametric) it is necessary to possess the competences in clusters general and x”. For instance, to be considered as an expert for detailed methodology competences in the general and detailed cluster have to be possessed.

When interviewing cost estimators, the author pointed out that competences within the same cluster (and methodology) are used in different frequency and have different difficulty level. It would be necessary to weight each competence against each cluster. Therefore, a second criterion addressing the grade to be considered as an expert for the methodology level should be set up. This work has not been carried out by this research due to the time and scope constraint.

4.6.1 Validation

Following question was formulated to cost estimators to validate the novice/expert approach (questionnaire 5 in ANNEX C):

1- Do you consider reasonable the approach of novice an expert presented (for competence and for methodology)? ☐ Yes ☐ No

The validation process was made individually to the users 1, 2, 3, 4, 5, 10 and 12 (see Table 3-1). After the explanation of the approach the question was formulated through questionnaire 5 in ANNEX C.The approach was accepted by the interviewed, as seen in the results presented in Table 4-20.

Table 4-20 Results from interviewed cost estimators on Novice/Expert

	1-Novice/expert approach
User 1	Yes
User 2	Yes
User 3	Yes
User 4	Yes
User 5	Yes
User 10	Yes
User 12	Yes

4.7 Tailoring the E-mentor (CE Process)

Using the consideration of novice and expert, the E-mentor tool (CE process) is tailored with the help files in terms of:

- Type of help.
- Compulsory display.

Each activity within the CE process can be related with one or many competences. For each competence a help file should be available. If the trainee is recognised as novice for a particular competence, which means they have level 1 or 2 in that competence, all the activities related with that competence will display the help file regarding the competence. This compulsory help file will pop-up just before the activity and will be available through a link during the activity. Otherwise, if trainee is recognised as an expert the help file will not be displayed before the activity but it will be available during the activity through a link.

4.7.1 Validation

To validate the help approach during the CE process (E-mentor tool) the following questions were addressed to cost estimators (see Figure 4-17).

E-mentor according trainee's expertise

1. Which kind of help would you like to see in the different screens of the e-mentor?

☐ Explanation of the meaning of each field and which type of element is required (number, date, etc.)

- An example of the screen filled (in order to see the type of elements required).
- Theoretical explanation of what is expected to do in each step.
- Example of the steps to carry on for a particular activity and so then be able to fill the screen.
- Other, please specify: ____________________

2- Do you agree of displaying the help material before the activities if you are considered

☐ Yes ☐ No

Figure 4-17 Questionnaire to validate the 'tailoring of the E-mentor'

Answers presented in Table 4-21 show some variability in terms of the help desired, but all users (see profile in Table 3-1) agreed in displaying automatically some help if trainee is recognised as novice.

Table 4-21 Answers to questionnaire presented in Figure 4-17

	1- Type of help					2- Agree with compulsory help for novice?
	Meaning filled	Exampled filled	Explanation activity	Example carry out activity	Other	
User 1	No	Yes	No	Yes	-	Yes
User 2	Yes	Yes	Yes	Yes	-	Yes
User 3	Yes	Yes	Yes	Yes	-	Yes, but he would like to see a difference in terms of content depending if trainee is novice or expert
User 5	Yes	Yes	Yes	Yes	-	Yes
User 10	No	No	No	Yes	-	Yes
User 12	Yes	Yes	Yes	Yes	-	Yes

4.8 Summary

As seen from the V-CES research context, there is a demand to create cost estimates. V-CES has deployed two top level resources to train cost estimators:

- Platform where training material is deployed (mainly courses).
- Cost Estimating (CE) E-mentor.

Thanks to the understanding of the V-CES project and the literature reviewed, the author identified that it is possible to bring intelligence in terms of guidance in different areas. Resources available can be tailored according the cost estimating situation and the cost estimator requirements.

Four main areas where identified:

- Suggestion of the CEM.
- Suggestion of the e-training path.
- Consideration of the trainee as an expert or novice.
- Tailoring the e-mentor process.

First area where to offer guidance is the suggestion of the CEM. It consists of a form to collect information regarding the project life cycle, data and resources available. According to the inputs of the form, the user is suggested the suitable CEMs to be carried out. This feedback considers the 3 CEMs available (analogy, detailed and parametric), the reasons why a CEM is not suitable and what should be obtained. The form was validated through interviewing eight cost estimators requesting from them to think of real examples they had to estimate the cost of. Through this exercise the feedback proposed by the e-mentor was also validated.

Second, it is the suggestion of the e-training path. This research has focused on the e-training path on the suggestion of available e-learning courses that fits the cost estimator needs. These needs are evaluated through the assessment of competences. The term competence is used by this thesis to refer to knowledge and skills, without considering attitude. The assessment uses the approach taken by the OGC (2004) when defining a set of knowledge and skills requested for competences in the management area. The level for each of the competences is obtained through knowing the percentage of knowledge and skills requested to be an expert. In parallel to the assessment of knowledge, it is possible to undertake a knowledge test to achieve a more objective result.

This third area where intelligence has been incorporated is the definition of novice or expert. Thanks to the assessment of knowledge and skills it has been possible to define the cost estimator as a novice or expert for each of the competences. As competences are grouped in 4 clusters: general, detailed, analogy and parametric, it would be possible to extend the definition of novice and expert at the methodology level.

Area four targets the E-mentor tool (as CE process) in terms of providing dynamic help when required. Activities within the CE process can be related with competences. Knowing if the trainee is novice or expert in competences and by creating help material for competence, it is possible to display the help material before undertaking the activity if the user is recognised as a novice.

This chapter has explained the framework where intelligence, in terms of guidance and tailor, has been applied. The selection of the areas and its development has been possible thanks to the author involvement on the research context, literature review and contact with cost estimators.

5 Implementation of the Framework

The previous chapter explains the research framework within the four core areas where intelligence has been applied. Each of them has been independently validated within the literature review and CE expertise. This chapter details the way in which the approach and framework has been implemented. The agents involved, the technical features and the tools developed are described within following sections. The sections are structured addressing these four main areas.

The technical architecture, network context, and enabling technologies are presented in Figure 5-1. They have been strongly influenced by the research context (V-CES). Technologies selected for V-CES include Apache as the External Web Server with the database services, MySQL as the database server and RDBMS to support the VLE and the cost database and Moodle as the VLE to create and deploy the training material (V-CES Consortium D1.5, 2005). The same technologies have been used in this study due to three main reasons:

- Areas of improvement are related with existing research context services or application (e.g Moodle platform).
- Easy and allows the integration of software developments (e.g. php coding).
- Availability and reuse of existing services (e.g. External Server)

In relation with the external or presentation level, PHP, a server-side scripting Web development language that can be embedded in HTML, has been selected (same than V-CES). PHP is an official module of Apache HTTP Server, and it allows connecting databases (implemented with MySQL) to Web pages (V-CES Consortium D1.5, 2005). Javascript functions have been used to provide dynamism to the php code.

The development of the e-training path, including the assessment of competences, is accessed through the platform provided by Moodle where the e-training material is deployed. The user is presented various forms (programmed with front end languages) where the information is requested. This information is stored in the 'Assessment database' and used by the rule based system to *suggest the e-training path* and to consider the trainee as a *Novice or Expert* (2 of the 4 areas where intelligence is applied).

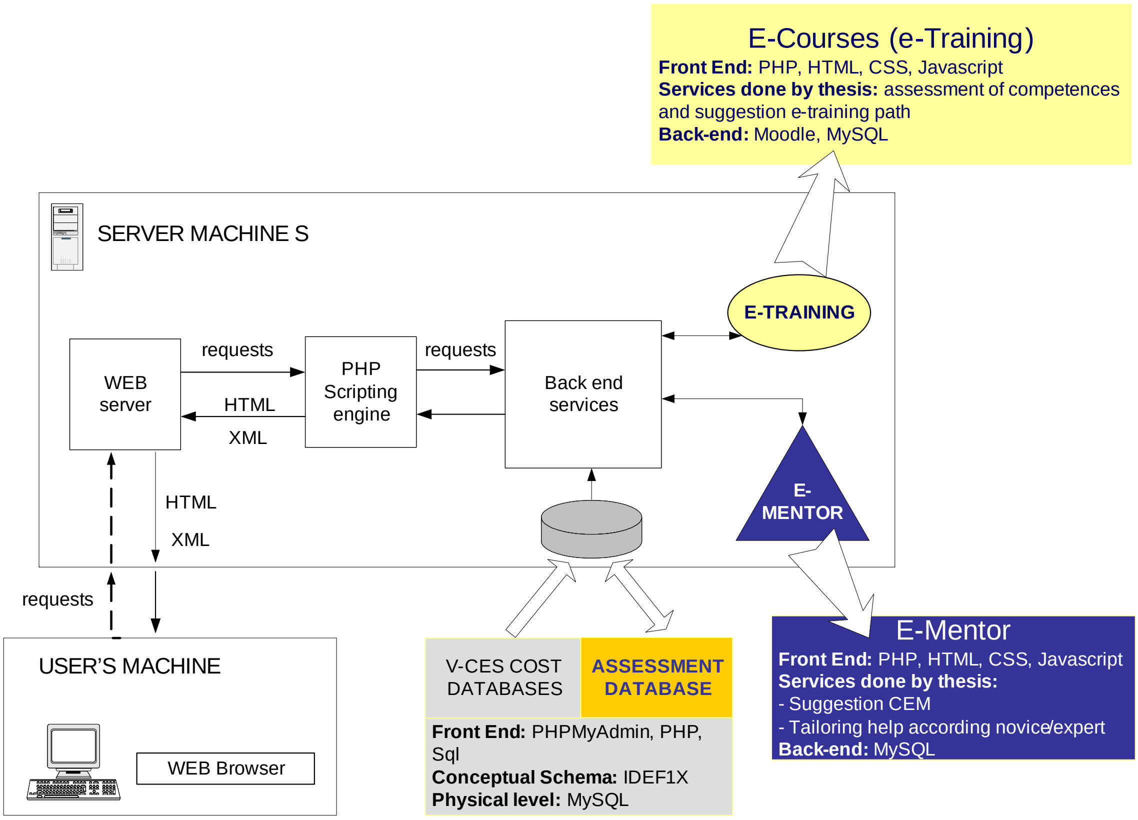


Figure 5-1 Technical structure implemented in the research

5.1 Suggestion of the Cost Estimating Methodology

The implementation of the framework for the suggestion of the CEM is explained along this section. It consists of two web-based screens coded with HTML, PHP and Javascript languages.

5.1.1 Implementation and Validation

The first screen (Screen 1, Figure 5-2) implements the content of the form presented in section 4.4 (see Table 4-4 and Table 4-5). It requests the information required to drive the rule-based system to get the appropriate feedback from the e-mentor.

A second screen appears after submitting the information on the first screen which presents the suggestion of the e-mentor with text explanations. One CEM has to be selected as a choice from the cost estimator. The feedback from the e-mentor is in terms of guidance, but the final decision has to be decided from the user.

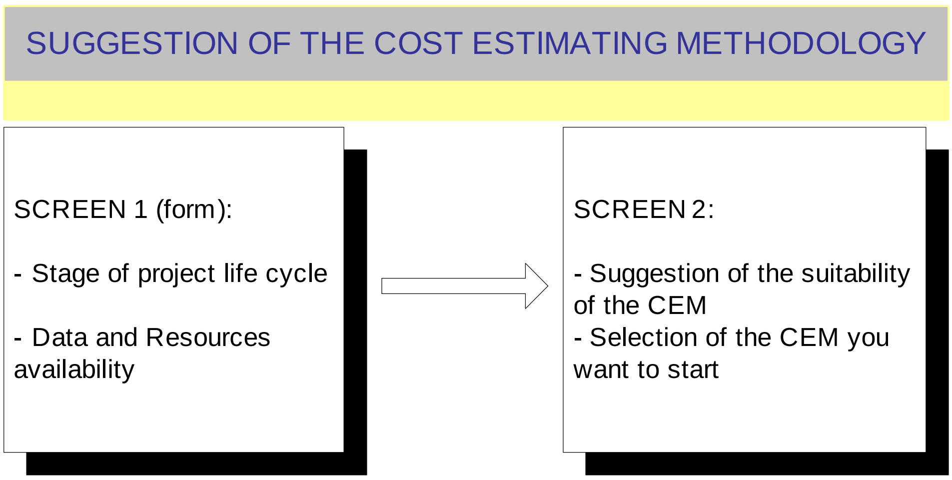


Figure 5-2 Web screens for the ‘suggestion of the CEM’

Figure 5-3 places the two screens together which builds the implementation of the Suggestion of the CEM. This is within the research context implementation (V-CES). Once the user logs into the system (V-CES), there is the possibility to create a new estimate, among others. Before deciding which CEM to use, access to the Suggestion of the CEM is available; otherwise, the user can start the process by selecting the desired CEM.

If the user decides to receive feedback from the e-mentor regarding the CEM to use, the two screens process presented in Figure 5-2 will be shown. After this, the choice of the CEM has to be completed and the CE process continues to different screens in which, the user has to input the data and parameters until the estimate has been successfully accomplished.

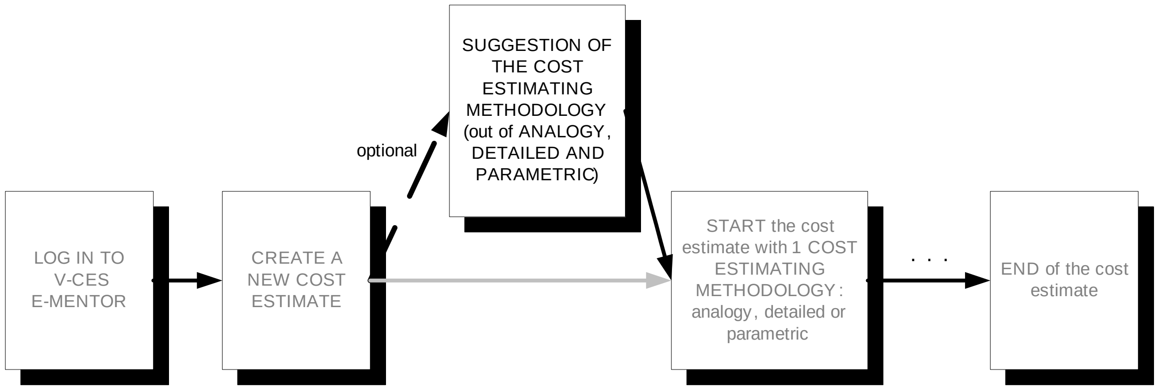
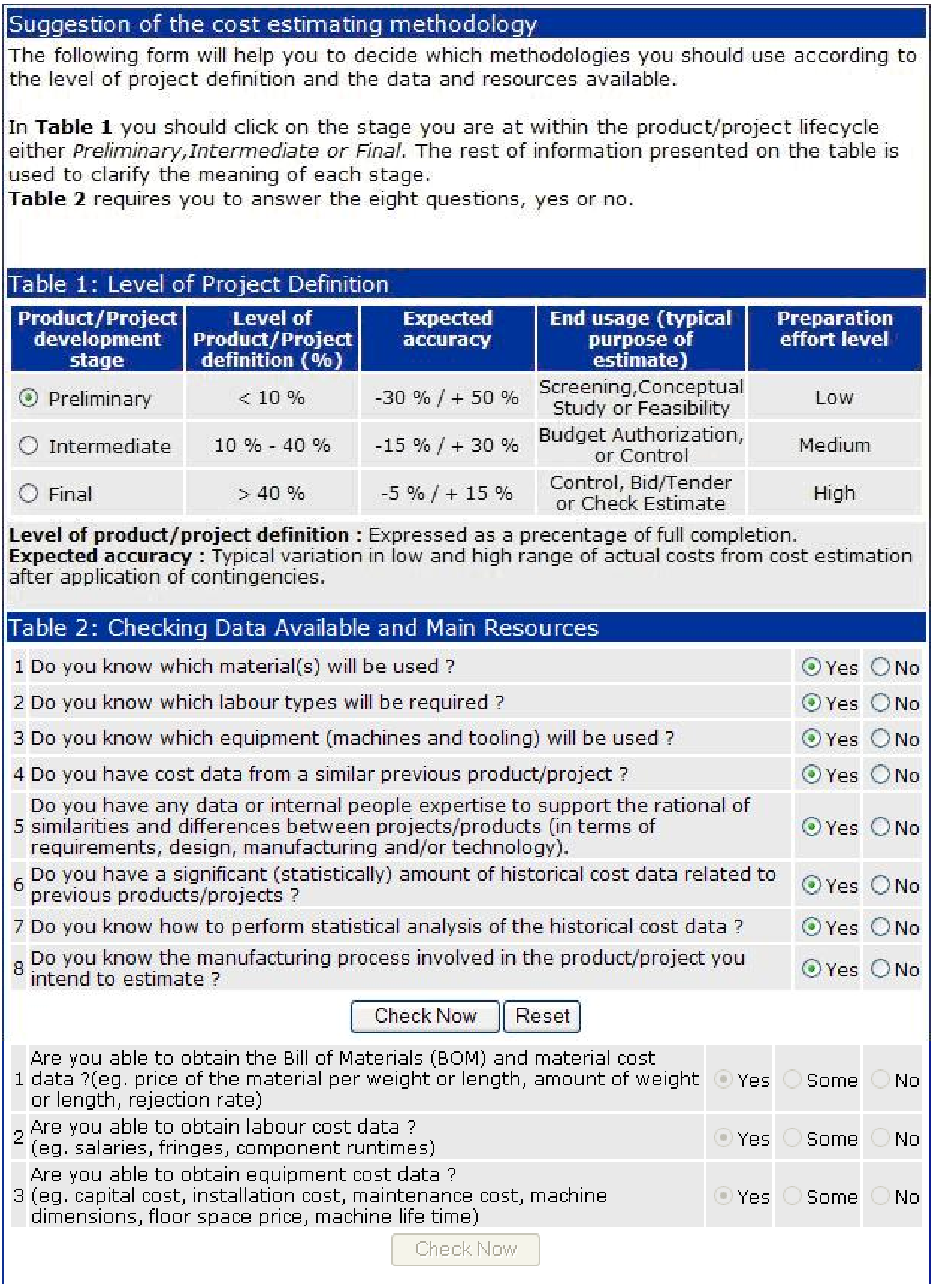


Figure 5-3 Placement of the ‘suggestion of the CEM’ within E-mentor tool (V-CES)

The implementation of the two screens that build this first area of intelligence is presented. The validation process and the results obtained are also shown and commented. Figure 5-4 is screen 1 (see Figure 5-2), which implements the form to receive the inputs from the cost estimator, requests information to suggest the suitable CEM according to project and the cost estimator requirements. This is the final form obtained after the validation process. Figure 5-5 shows the implementation of the feedback screen (screen 2 in Figure 5-2) where the suggestion of the CEM and the recommendation are presented to the user.



Suggestion of the cost estimating methodology

The following form will help you to decide which methodologies you should use according to the level of project definition and the data and resources available.

In **Table 1** you should click on the stage you are at within the product/project lifecycle either *Preliminary,Intermediate or Final*. The rest of information presented on the table is used to clarify the meaning of each stage.
Table 2 requires you to answer the eight questions, yes or no.

Table 1: Level of Project Definition

Product/Project development stage	Level of Product/Project definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level
Preliminary	< 10 %	-30 % / + 50 %	Screening,Conceptual Study or Feasibility	Low
Intermediate	10 % - 40 %	-15 % / + 30 %	Budget Authorization, or Control	Medium
Final	> 40 %	-5 % / + 15 %	Control, Bid/Tender or Check Estimate	High

Level of product/project definition : Expressed as a precentage of full completion.
Expected accuracy : Typical variation in low and high range of actual costs from cost estimation after application of contingencies.

Table 2: Checking Data Available and Main Resources

1	Do you know which material(s) will be used ?	Yes	No
2	Do you know which labour types will be required ?	Yes	No
3	Do you know which equipment (machines and tooling) will be used ?	Yes	No
4	Do you have cost data from a similar previous product/project ?	Yes	No
5	Do you have any data or internal people expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).	Yes	No
6	Do you have a significant (statistically) amount of historical cost data related to previous products/projects ?	Yes	No
7	Do you know how to perform statistical analysis of the historical cost data ?	Yes	No
8	Do you know the manufacturing process involved in the product/project you intend to estimate ?	Yes	No

Check Now Reset

1	Are you able to obtain the Bill of Materials (BOM) and material cost data ?(eg. price of the material per weight or length, amount of weight or length, rejection rate)	Yes	Some	No
2	Are you able to obtain labour cost data ? (eg. salaries, fringes, component runtimes)	Yes	Some	No
3	Are you able to obtain equipment cost data ? (eg. capital cost, installation cost, maintenance cost, machine dimensions, floor space price, machine life time)	Yes	Some	No

Check Now

Figure 5-4 Screen 1: Form to get the inputs to suggest the CEM

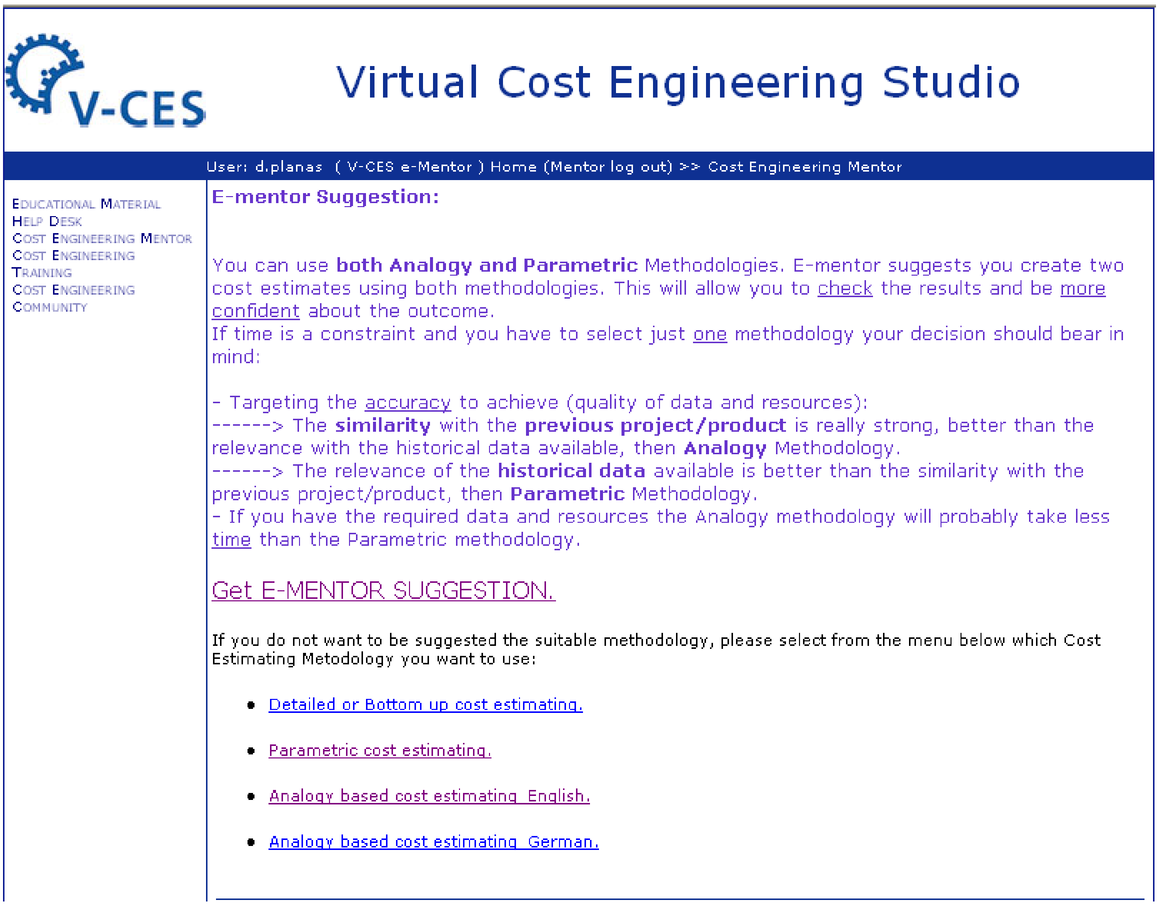


Figure 5-5 Screen 2: Feedback from the e-mentor to suggest the CEM

The validation process for the implementation had two main purposes:

1- Final validation of the content of:
   - The form (screen 1).
   - The feedback provided (screen 2).
2- High level validity of interfaces in terms of screen appearance and usability.

It consisted of individual interviews with 8 cost estimators (all involved in the framework validation, see Table 3-1) supported with questionnaires (with open and closed questions).

Even if the users went through the validation of the framework which involved the validation of the content (see Table 4-4 and Table 4-5), the validation of the content of the form (screen 1 in Figure 5-4) was pointed out to be worthy at the implementation stage for the following reasons:

1- Having to physically decide the answers by clicking check boxes. The user is placed into the real context of what they have to do.
2- Being able to go back to the questions after receiving the feedback and to think about it. This was the main reason of the importance of validating the content in the implementation stage.

The interview and questionnaire were also based on real examples that they had to estimate. This provided to be the best approach to maximise the validity of the application.

The questionnaire to receive feedback and validate the implementation of the form is presented in Figure 5-6.

1. Do you feel comfortable with the screen appearance?
2. Think of a real example that you had to estimate.
    a. Name the type of project/product:
    b. Answer to:
        i. Stage of the project life:
        ii. Q1=
        iii. Q2=
        iv. Q3=
        v. Q4=
        vi. Q5=
        vii. Q6=
        viii. Q7=
        ix. Q8=
        x. QD1=
        xi. QD2=
        xii. QD3=
    c. Are you satisfied (do you agree) with the answer received? Why if not?

    [Exercise 2 was done from 3 to 6 times depending on the availability of time]
3. Have you had any doubt when answering the forms? If yes which?
4. Do you find useful the suggestion of the methodology from the e-mentor?

Figure 5-6 Questionnaire to validate the implementation of the 'suggestion of the CEM'

Table 5-1 presents the target of the questions when defining the form presented in Figure 5-6 to validate the implementation of the suggestion of the CEM.

Table 5-1 Target of the questions on the form presented in Figure 5-6

Question	Target
1	Validation of the **interface**: understandable and easy to fill.
2	Validation of the **questions**: requirements/questions.
3	Validation of the **questions**.
4	Validation of the **feedback**: correctness and usefulness.
5	Validation of the **implementation** in general.

A summary of the answers from the questionnaire is presented in Table 5-2 (detailed answers available in ANNEX C).

Table 5-2 Results from the questionnaire presented in Figure 5-6

	General Improvements (summarise)
Screen appearance	- Too busy. Separate the form into 2 screens.
Section 1: Project life cycle table	- Delete the numerical values in level of effort. If the purpose is to give a qualitative view, the names are enough. Keep just: low, medium and high.
Section 2: Data/ Resources available	- Q1: Leave the word materials and get rid off the word BOM. - Q2: ok - Q3: Add tooling in the definition of equipment a part from machining. - Q1, Q2 and Q3: Add something like <u>all</u> to avoid the user have the desire to answer some. - Q4: ok. - Q5: add <u>people</u> to refer to the internal expertise. - Q6: ok. When saying statistically people doubt if they have enough. - Q7: Redefinition of the question. In fact system does not care if you use a software package or you do it manually. The only concern is if you know how to do a statistical analysis. Question will be completely redefined according to this. - Q8: Question not clear. Add the work manufacturing and remove project life cycle. - QD1: ok. As some users defined the content into brackets as the BOM and the desire to see BOM somewhere was manifested → add the word BOM in the question. - QD2: Change “timing component required” by “component runtimes”, as first one is too ambiguous. - QD3: ok.

The following comments were presented after receiving feedback from the interviewees regarding the content of the form:

- Numerical values and key names used in Section 1 would not be expected to be changed as the approach taken is proposed by AACE. Small changes will be addressed to understand the options.

- Q7: some people just answered ‘no’ because either they did not perform a statistical analysis or because they got confused thinking it was software similar to Price-H. Most of them they did not think about using Excel in performing this. Therefore, answering ‘no’ is not correct as they do have a tool to do it (as Excel), but they do not really know how to do it.
- Q1, Q2 and Q3 → SOME have been included to the table as data can be provided in terms of materials, labour and equipment. In terms of rules, it depends if the user is in the preliminary or final stage as some of the criteria is making different rules. For questions QD1, QD2 and QD3, there is no SOME as it is not leading to any help action to differentiate the CEM to use.
- Feedback: When conducting the interview, the author was putting an emphasis in knowing if they liked the main drivers of the criteria to suggest the CEM (section 4.4.2). Nine interviewed users agreed on the 5 items (see questionnaire 4 of ANNEX C).

There was no added content in terms of changing the type of data or resources required, but it was pointed out that some of the questions needed to be rewritten to make sure they were understood by users (see Figure 5-7).

Level of Project Definition

Product /Project development stage	Level of project/ product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level	MEC
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	**Low**	Analogy Parametric
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	**Medium**	Analogy Parametric Detailed
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	**High**	Detailed

Checking Data available and main Resources

1 – Do you know which material(s) will be used?
2 - Do you know which labour types will be required?
3 - Do you know which equipment type (machines **and equipment**) will be used?
4 - Do you have cost data from a similar previous product/project?
5 - Do you have any data or internal **people** expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).
6 - Do you have a significant (statistically) amount of historical cost data related to previous products/projects?
7 - **Do you know how to perform statistical analysis of the historical cost data**?
8 -Do you know the **manufacturing** process involved in the product/project you intend to estimate?

1 – Are you able to obtain material **the BOM and** cost data? (e.g. price of the material per weight or length, amount of weight or length, rejection rate)
2 - Are you able to obtain labour cost data? (e.g. salaries, fringes, **component runtimes**)
3 - Are you able to obtain equipment cost data? (e.g. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time)

Figure 5-7 Changes on the form (* changes in bold)

The following comments were concluded after receiving feedback from the interviewees regarding the screen appearance:

- The following suggestion: “Split the form in two screens” could be implemented (though it is not presented in this thesis). The first screen would contain section 1 and a second screen would present section 2.

- There was a suggestion to just show the variable ‘project/product development stage’ (preliminary, intermediate and final) and leave the rest as a help option if user does not understand what concepts mean. This would not be implemented; as experience when doing the validation probed that cost estimators may understand differently the terms Preliminary, Intermediate and Final. It is important that the decision of the name is based on the data annexed.

5.2 Suggestion of the E-training Path

The previous section details the implementation process for the area of ‘suggesting the CEM’ and its validation. The implementation of the area to ‘suggest the e-training path’ is explained in this section. The implementation process starts with; the definition of the requirements through the analysis of the system and then moves to what can be used and linked to the research context (V-CES), and what has to be developed. The validation process has been completed together with the two other areas of intelligence: ‘trainee as novice/expert’ and ‘tailoring of the CE e-mentor’ in a Case Study which is presented in Chapter 6.

5.2.1 Implementation

The purpose of this area, where to bring intelligence, is to suggest the e-training path. At this level, this study is defining the e-training path as the courses that fulfil the trainee needs and interests. In order to work out the trainee needs and interests, an ‘Assessment of the competences’ has been designed and implemented as described in chapter 4.

Before starting to define the interfaces, the requirements and the interaction of the system with the outside were defined. The use-case diagram depicted in Figure 5-8 identified the requirements of the system interfaces (what it should do) and who interacts with it and helped to verify that all requirements were captured and developed. All actors or agents that interact with the system and the use cases (actions a system performs) were drawn.

Five actors were identified within the system are: trainee, mentor (or teacher), cost estimator expert, administrator and e-mentor.

E-mentor is a virtual actor which is in command to provide the intelligence to the system, both assessing the trainee competences and suggesting the e-training path. The way it operates is by following the rules programmed in the code behind the interface screens. The administrator has the rights to register new users (mentors and trainees) and enrol trainee on courses. They also have to enter into the system, the competences, knowledge and skill (K&S) and the test of knowledge as defined by the cost estimator expert. The cost estimator expert defines some of the content of the system but does not directly interact with it. The mentor (or teacher) is in charge of defining the e-courses and match them with the competences that target it. The three actors: administrator, trainee and mentor physically interact with the system; a login action to identify them is required.

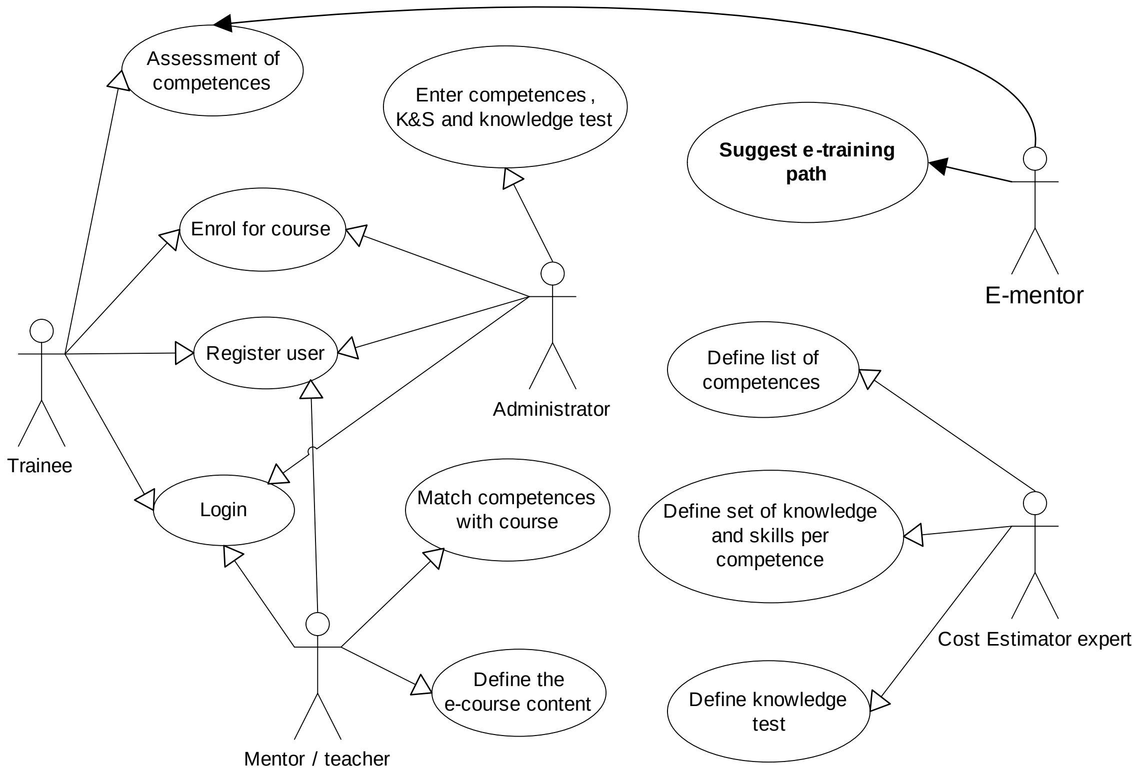


Figure 5-8 Use-case diagram for the ‘suggestion of the e-training path’

The three roles: trainee, mentor/teacher and cost estimator expert are explained in more detail as depicted in Figure 5-9.

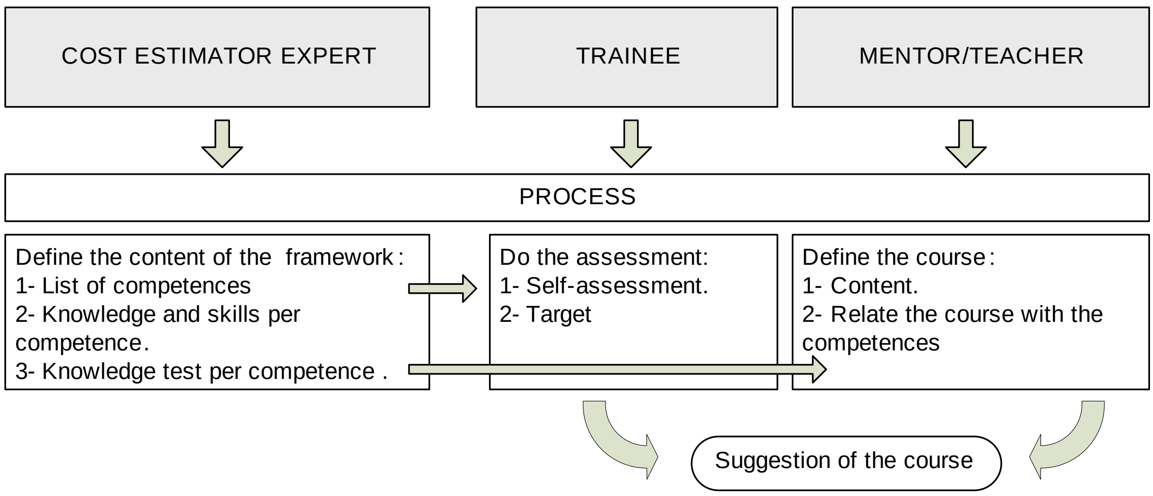


Figure 5-9 Roles within the research framework

COST ESTIMATOR EXPERT

The process from ***cost estimator expert*** point of view is to:

1- Define the set of competences required for the cost estimating discipline. Add a description per each one.

2- Define the set of knowledge and skills required to be an expert on that competence.

3- Define a test (between 5-10 questions) to assess the knowledge for each competence. It is important that reflect the set of knowledge identified in step 2.

TRAINEE

Process from ***trainee*** point of view (see Figure 5-10):

1- Do the self-assessment per each competence. The current level (1-2-3-4) for each competence has to be identified. There are two different ways of getting the value.

a) Enter it manually according to the generic definition of each level (1-2-3-4).

b) Make use of the system assessment.

b.1) Select the knowledge and skills possessed.

If it is decided to do the system assessment, the level obtained on that competence will not be able to be changed manually. If it was previously entered manually, the system will update it with the level achieved when performing the system assessment.

b.2) If it is desired to better test the knowledge, a test to assess the level of knowledge can be performed (voluntary). The test can just be done once. Between the test of knowledge and the set of knowledge, the lower of the two levels achieved will be taken.

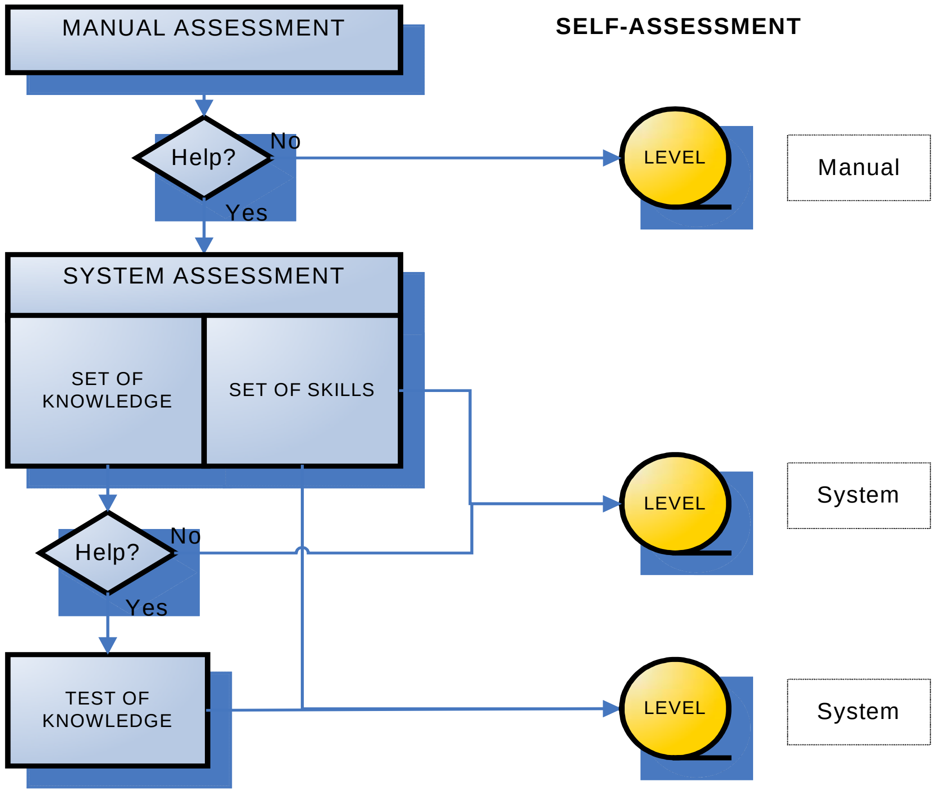


Figure 5-10 Assessment process from trainee point of view

2- Assessment of the target level

MENTOR / TEACHER

Process from ***mentor/teacher*** point of view:

1- Creation of a course: defining its content.
2- Select which competences are related with the course and in which levels (1-2-3-4).

The actors and actions identified in Figure 5-8 depict all the requirements for the system approach in the suggestion of the e-training path. As this area is found and linked to the research context (V-CES), the use of the VLE has influenced many of the decisions on the study implementation. The VLE defined by V-CES using the Moodle platform was already deployed with the following actions (see Figure 5-8):

- Login (for trainee, mentor and administrator).
- Enrolment of courses.
- Register of user (trainee, mentors and administrator).
- Definition of the e-course content.

To avoid the duplicity of actions and the possibility to generate a well integrated system, a deep study of how to make use of these services and link them with the new actions required was carried out.

The suggestion of the e-training path together with the assessment of the competences is accessed as a new resource within the VLE platform defined with Moodle by V-CES (see Figure 5-11). Because of the restrictions in modifying the content of the Moodle database and coding files, only reading of the database has been used. The forms to assess the competences and suggest the e-training course have been generated from scratch and no reuse of Moodle functionality has been possible. Therefore, a new database to store the assessment of competences and suggested courses has been implemented with MySQL (see Figure 5-11 'Assessment database').

Figure 5-11 depicts the integration between VLE platform provided by the research context and the new study requirements.

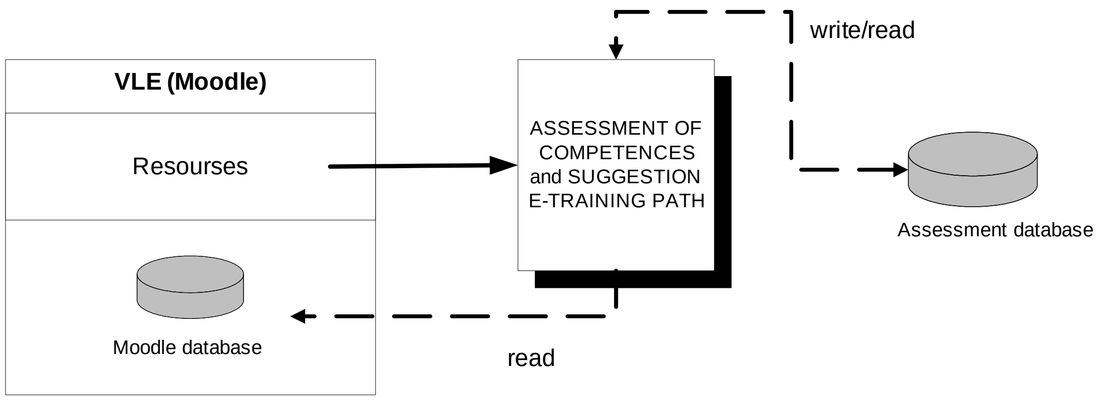


Figure 5-11 Integration of VLE platform and new research requirements

The IDEF1X diagram of the 'Assessment database' is shown in Figure 5-12. Tables TRAINEE, TRAINEE_TM and TRAINING_MATERIAL are implemented within the Moodle database (see in green, pink and blue respectively). The rest of the tables have been created to build the ‘Assessment database’. Each table is represented by a square and the names is presented on the top grey label. Within each table the various fields names are shown.

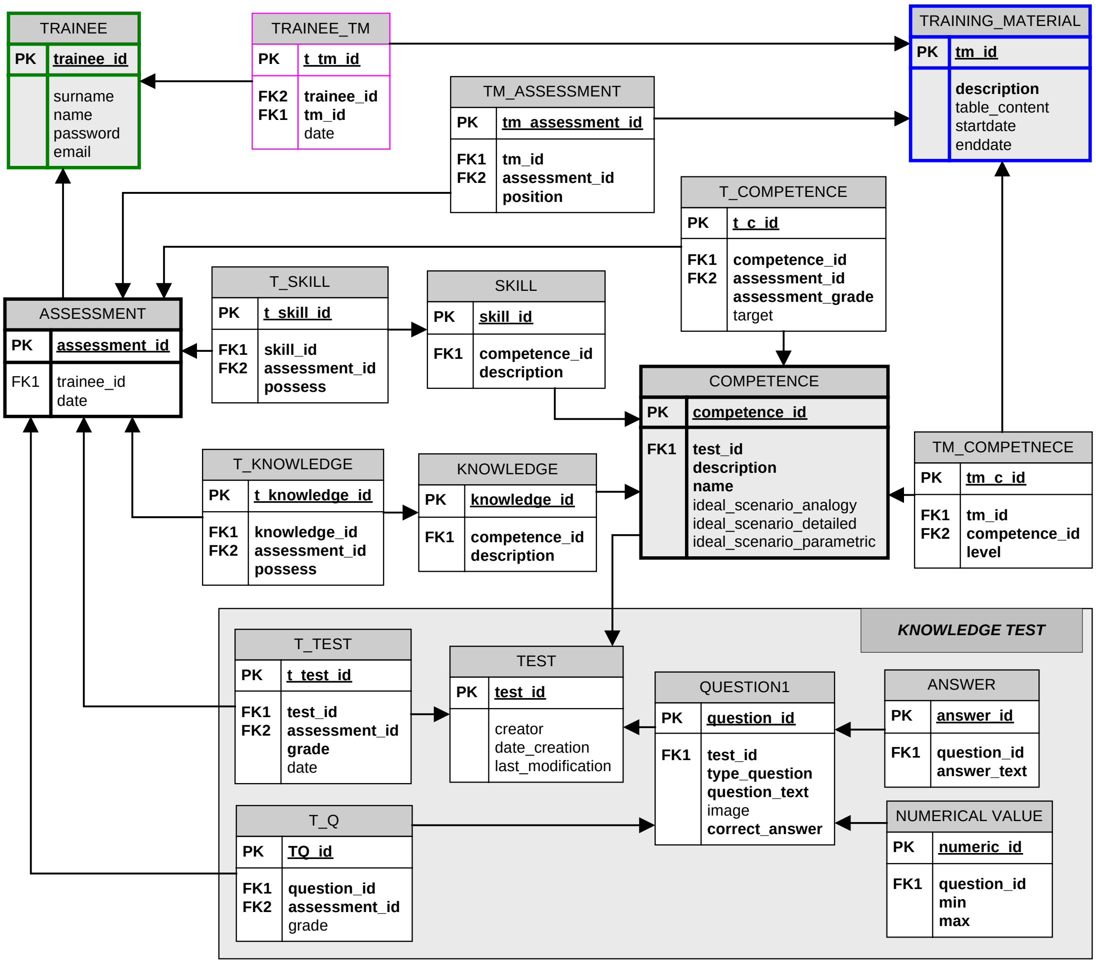


Figure 5-12 IDEF1X diagram for ‘Assessment database’. [PK]: Primary key [FK]: Foreign key

For the actions: “enter competences, K&S and the knowledge test” and “match competence with course” (see Figure 5-8), no interfaces have been developed to access the database “Assessment database”. Therefore, these actions have to be completed by entering the information directly into the database.

The actions, “Assessment of competences” and “suggestion of the e-training path” (see Figure 5-8), demanded the deployment of new screens. These two are the actions that directly bring intelligence to the system and which are linked to the e-mentor actor.

The screens and their relations are represented in Figure 5-13. Web-based screens are coded with html, php and Javascript languages. Php is used to transfer the information between the Web screens and the MySQL databases.

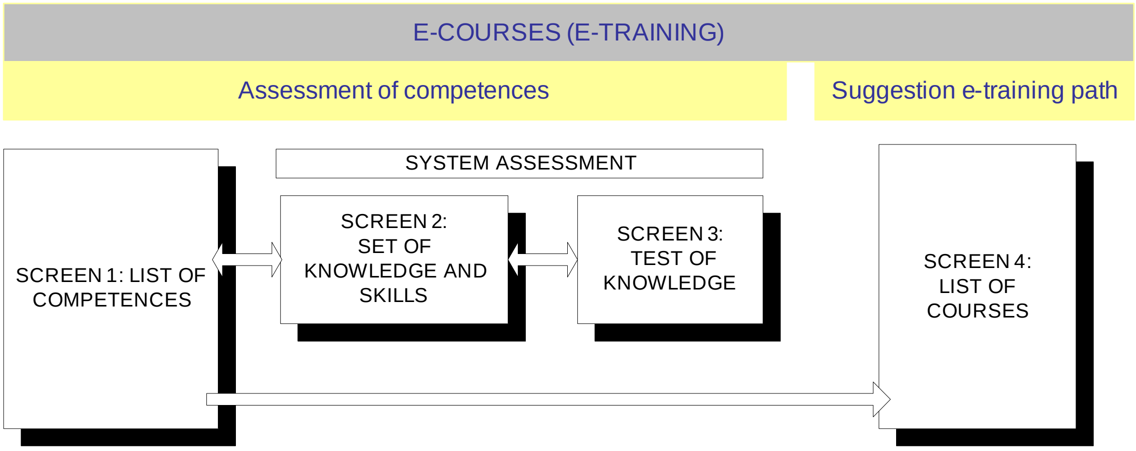
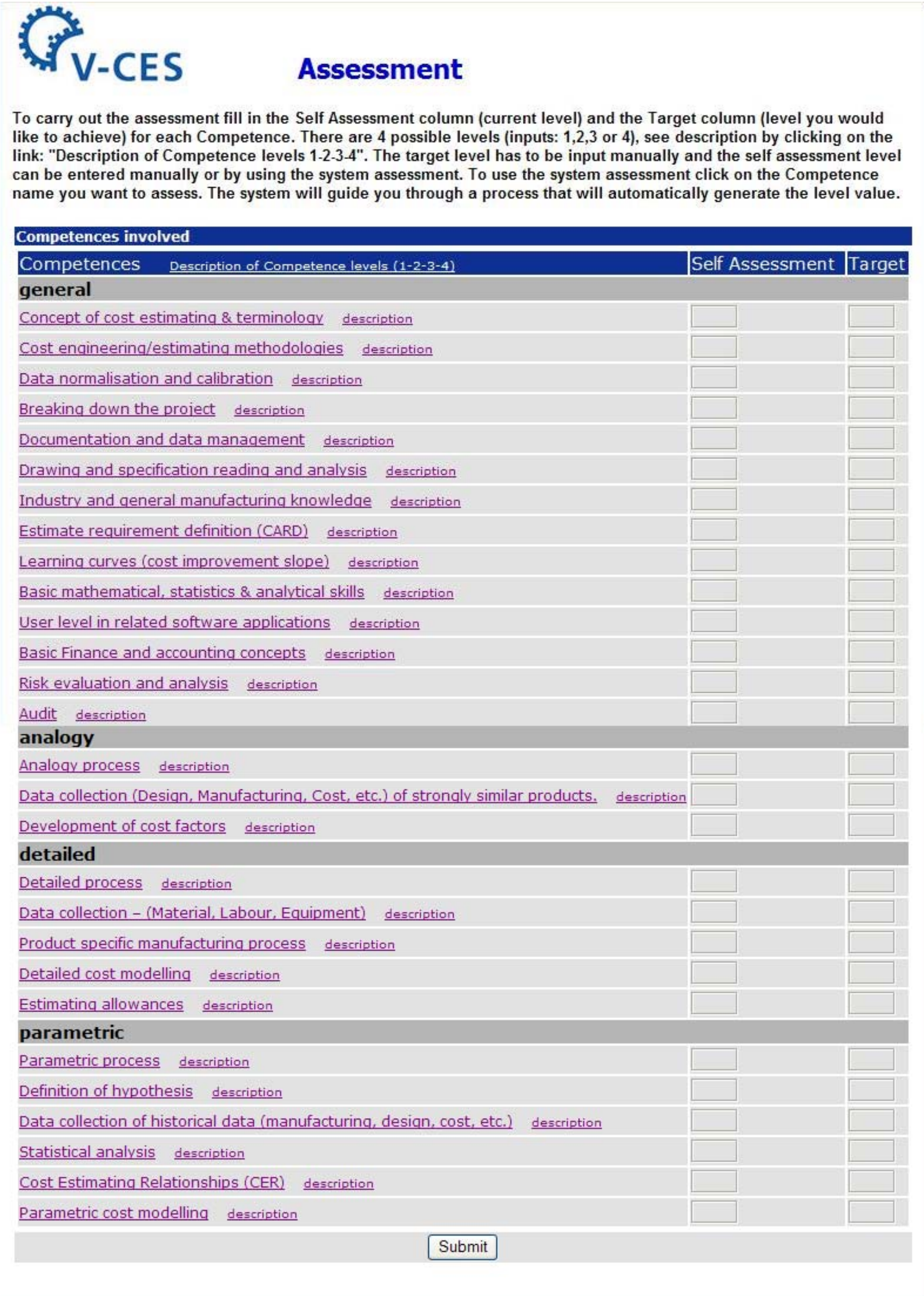


Figure 5-13 Web screens for 'suggestion of the e-training path'

The "Assessment of competences" begins with a first screen where the list of competences is presented (see Figure 5-14). A top paragraph above the table of competences briefly describes what to do in the screen. A link, "Description of the competence levels 1-2-3-4", presents a table where 4 levels to assess the competences are described (with the content shown in Table 4-16). Self-assessment (current level) and the target level (what you like to achieve) has to be defined by the trainee on each of the competences. A link next to each competence (named as "description") describes the competence.



V-CES

Assessment

To carry out the assessment fill in the Self Assessment column (current level) and the Target column (level you would like to achieve) for each Competence. There are 4 possible levels (inputs: 1,2,3 or 4), see description by clicking on the link: "Description of Competence levels 1-2-3-4". The target level has to be input manually and the self assessment level can be entered manually or by using the system assessment. To use the system assessment click on the Competence name you want to assess. The system will guide you through a process that will automatically generate the level value.

Competences involved

Competences Description of Competence levels (1-2-3-4)	Self Assessment	Target
general		
Concept of cost estimating & terminology description		
Cost engineering/estimating methodologies description		
Data normalisation and calibration description		
Breaking down the project description		
Documentation and data management description		
Drawing and specification reading and analysis description		
Industry and general manufacturing knowledge description		
Estimate requirement definition (CARD) description		
Learning curves (cost improvement slope) description		
Basic mathematical, statistics & analytical skills description		
User level in related software applications description		
Basic Finance and accounting concepts description		
Risk evaluation and analysis description		
Audit description		
analogy		
Analogy process description		
Data collection (Design, Manufacturing, Cost, etc.) of strongly similar products. description		
Development of cost factors description		
detailed		
Detailed process description		
Data collection – (Material, Labour, Equipment) description		
Product specific manufacturing process description		
Detailed cost modelling description		
Estimating allowances description		
parametric		
Parametric process description		
Definition of hypothesis description		
Data collection of historical data (manufacturing, design, cost, etc.) description		
Statistical analysis description		
Cost Estimating Relationships (CER) description		
Parametric cost modelling description		

Submit

Figure 5-14 Screen 1 from Figure 5-13 with list of competences

The self-assessment level can be obtained through a system assessment. It begins with screen 2 (see Figure 5-13) after clicking the name of the competence desired to assess (in Figure 4-15) where two tables are shown (see Figure 5-15). The first table displays the set of knowledge required on that competence and a second table provides the skills. The trainee is required to answer by selecting ‘yes’ or ‘no’ on each of the knowledge and skills. Answering ‘yes’ means they possess that knowledge/skill and ‘no’ that they do not. The submission of that screen brings the user to screen number 1 providing the self-assessment level on the competence assessed (see Figure 5-13). Otherwise, from screen 2 there is the possibility to undertake a test to assess the knowledge on the competence. By clicking the link: “I would like to do a TEST”, the trainee is directed to screen 3 (see Figure 5-13 and Figure 5-16).

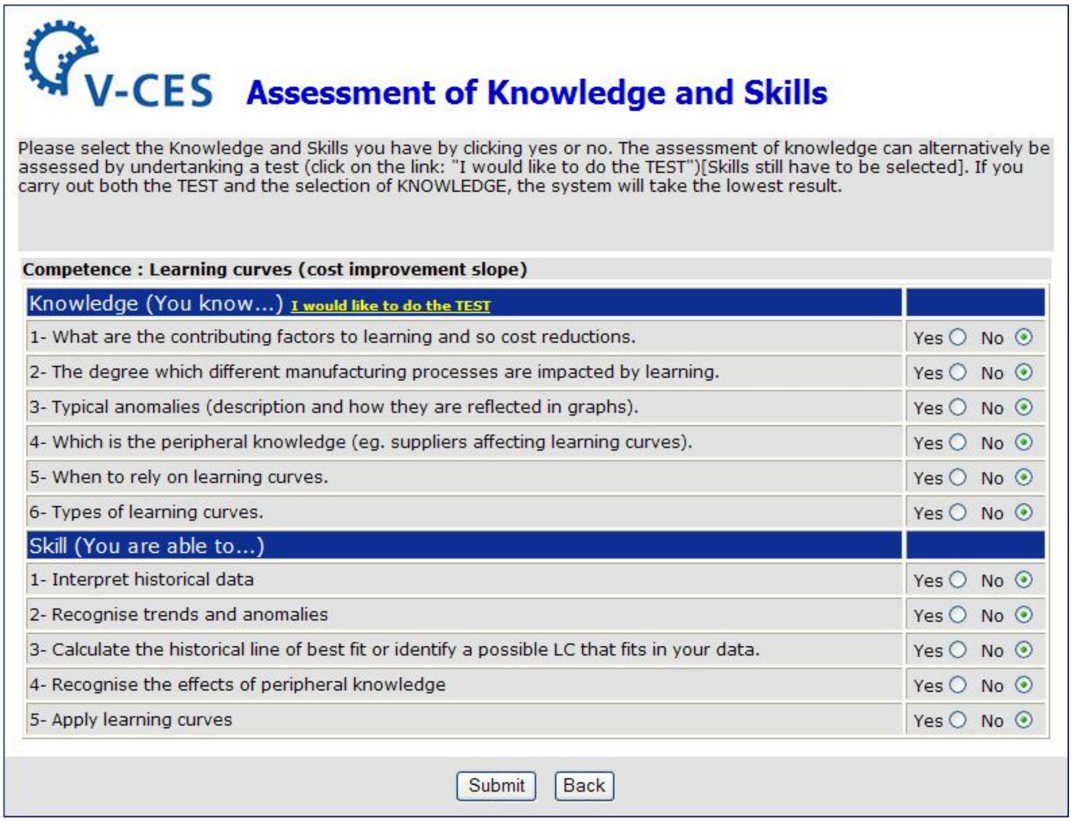


Figure 5-15 Screen 2 from Figure 5-13 with set of knowledge and skills

The knowledge test is formed by 3 types of questions: numerical, multiple choices and true/false. The reason is to constrain the difficulties on the screen presentation and correction criteria made by the e-mentor. For instance, a question which requests the trainee to draw on a graph is not accepted.

By submitting the knowledge test (screen 3) the trainee sees which questions were answered correctly and incorrectly (right side on Figure 5-16). The criterion to obtain the score out of the test is the following in order to quantify up to zero, the possibilities to guess the answers randomly:

- A correct answer will add +1
- An in correct answer will subtract:
  - Numerical type: -0
  - Multiple choice: -1/(number of answers -1) → True/False: -1

Final score will be ranged to a maximum of 10 points.

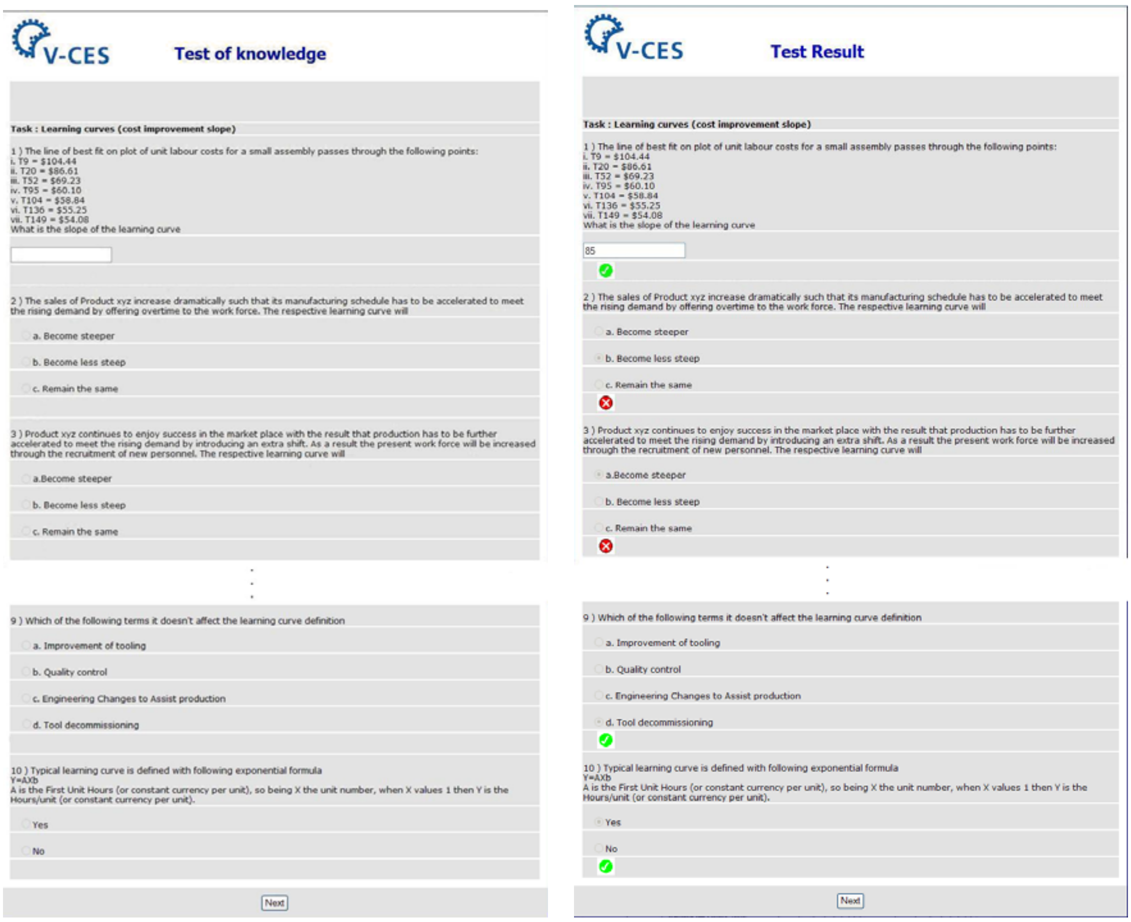


Figure 5-16 Screen 3 from Figure 5-13: Test of knowledge (left side before answer and right side after e-mentor correction

The submission of screen 3, once corrected (right side of Figure 5-16), directs the trainee to screen 2 (see Figure 5-13 and Figure 5-15) where they can see the score obtained in the knowledge test. Some rules on the coding define the self assessment level on the competence. After this process is completed for all competences, the submission of screen 1 leads the trainee to screen 4 (see Figure 5-13 and Figure 5-17), where the list prioritizing courses (e-training path) is shown.

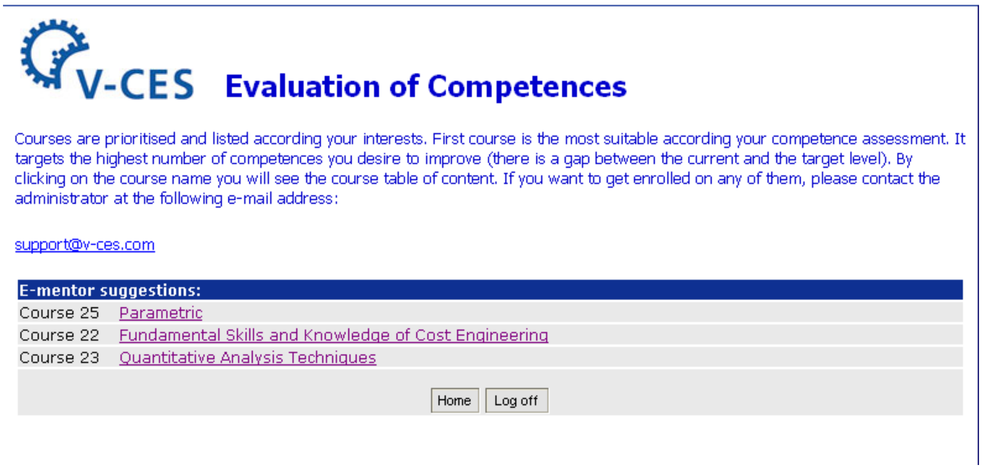


Figure 5-17 Screen 4 from Figure 5-13: E-training path (e-courses fulfilling trainee interests)

Each course name is a link to its table of content as shown in Figure 5-18, for the course: “Fundamental Skills and Knowledge of Cost Engineering”.

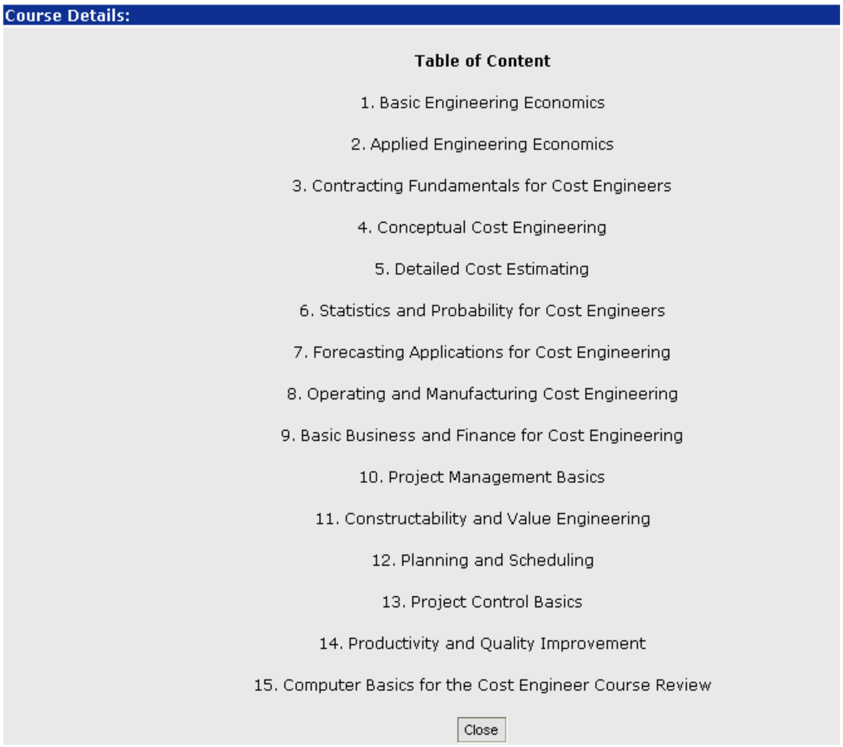


Figure 5-18 E-course (table of content): ‘Fundamental Skills & Knowledge of Cost Engineering’

5.3 Trainee as Novice or Expert

The previous section details the implementation process and its results for the area of ‘Suggesting the e-training path’. This section explains the area of considering the ‘trainee as a novice or expert’. The validation process has been completed together with the two other areas of intelligence: ‘suggestion of the e-training path’ and ‘tailoring of the CE e-mentor’ in a Case Study presented in Chapter 6.

5.3.1 Implementation

The consideration of the trainee (cost estimator) as a novice or expert is completed, as explained in the framework section 4.6, using the assessment of the competences defined in previous section 5.2. The information about the self-assessment level (current) for the competences leads to the definition of novice and expert on the competence level. The assessment on the competence is the same as explained in previous section 5.2 (see Figure 5-13). Figure 5-19 presents a user-case diagram with the actions and actors involved in classifying the trainee as novice or expert. Therefore, to be able to use this classification, the competence assessment has to be undertaken. This is required only once as the first step for the two areas of intelligence: ‘suggestion of e-training path’ and ‘trainee as novice or expert’.

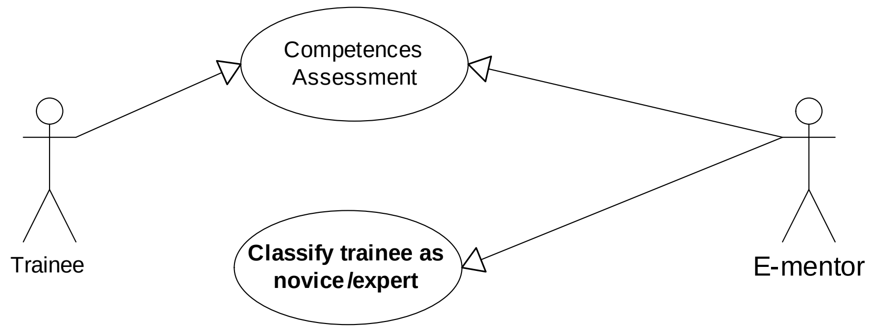


Figure 5-19 User-case diagram for ‘trainee as novice/expert’

By querying the ‘Assessment Database’ (see Figure 5-20) with the self-assessment level for the relation trainee competences, the system identifies the trainee as novice or expert in the way depicted in Figure 4-16.

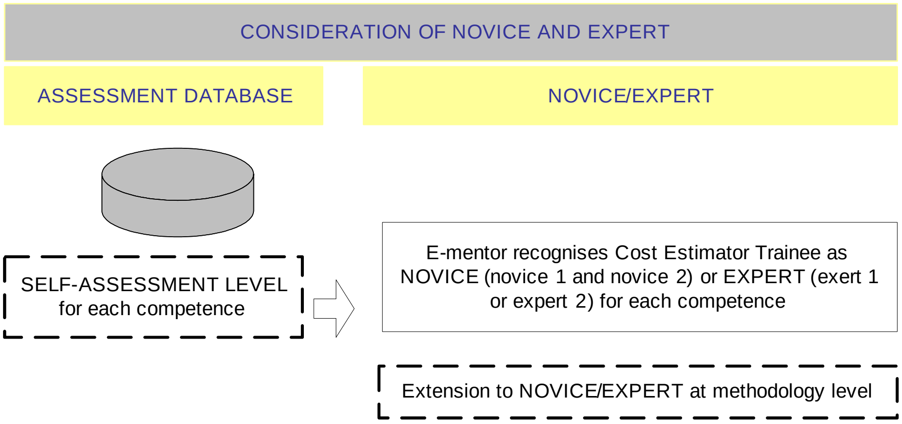


Figure 5-20 Elements involved in ‘trainee as novice/expert’

Chapter 6 defines a test scenario to implement the prototype within the Cost Estimating discipline. One of the developments is the definition of the list of competences required to carry out the CE process based on the 3 CEMs: analogy, detailed and parametric. The competences are clustered in the 3 CEMs to lead to future implementation of the recognition of the trainee as novice and expert at the CEM level. This would enable to undertake the necessary actions at the methodology level, for example, to implement the whole CE E-mentor tool differently according if it is novice or expert for each CEM.

5.4 Tailoring the E-mentor (CE Process)

The previous section defines the ‘trainee as novice or expert’ at the competence level. As the competences targeted by this research address the CE process based on the 3 CEMs: analogy, detailed and parametric, it is possible to link the activities required using the V-CES e-mentor with the competences. If the trainee is identified as a novice or an expert in the competences linked to that activity, it then becomes possible to undertake actions.

The validation process was completed with two other areas of intelligence: ‘suggestion of the e-training path’ and ‘trainee as novice/expert’ in a Case Study presented in Chapter 6.

5.4.1 Implementation

This study provides actions in terms of help. As defined in section 4.6 of the framework, if the trainee is considered as a novice in the competences related to the activity, the e-mentor will display some help before the activity starts. This help would be available during the activity either if the trainee is considered as a novice or expert.

The user-case diagram depicted in Figure 5-21 shows the actions undertaken by the 3 actors involved in this area of ‘tailoring the CE process’ in terms of help: trainee, cost estimator expert and e-mentor. The trainee logs into the system and carries out the CE process as defined by the research context (E-mentor tool in V-CES). The cost estimator expert has to decide which competences are linked to the activities. The e-mentor provides intelligence by querying the database to recognise the trainee as novice or expert and delivering help when requested. The system is controlled by a rule-based system programmed behind the interface screens.

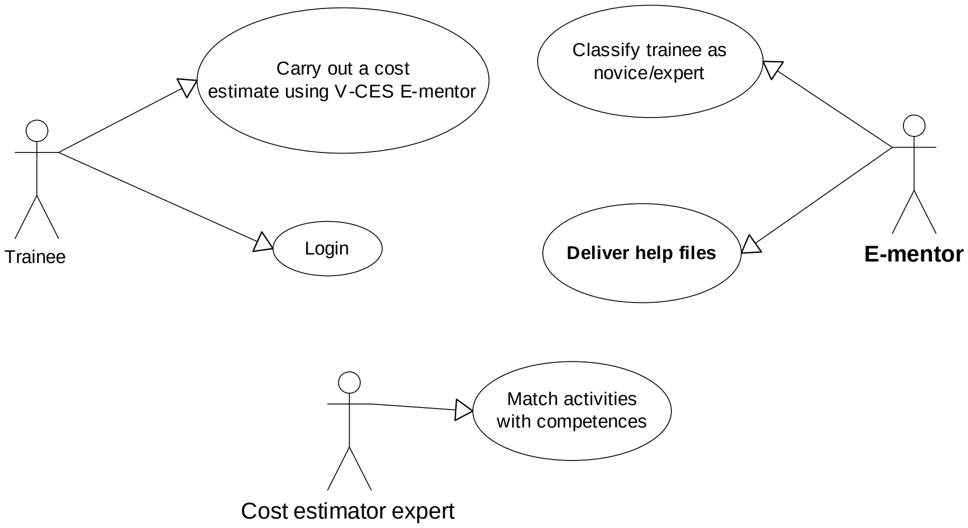


Figure 5-21 User-case diagram for ‘tailoring the E-mentor (CE process)’

Figure 5-22 depicts the way the system has been implemented. Before the trainee starts using the tool (carrying out the CE process with E-mentor as defined by V-CES), the help files and the coding to link activities and competences have to be defined. The e-mentor, by a rule-based system, checks before carrying out an activity if there are any competences linked to it and if the trainee is novice or expert in them.

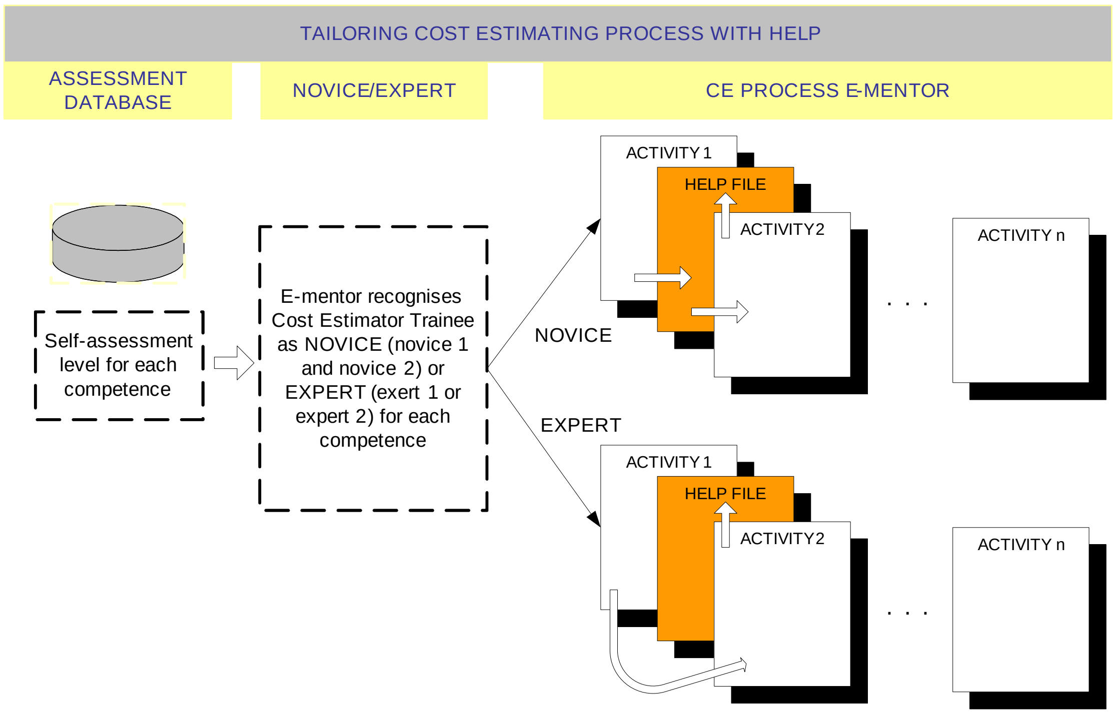


Figure 5-22 Elements / web screens involved in 'tailoring the E-mentor (CE process)'

For instance (see Figure 5-22), after carrying out activity 1, the e-mentor checks the competences linked to activity 2. If trainee is identified as a novice on these competences, the correspondent help files are shown in the screen named "HELP FILE". The submission of this help screen leads the trainee to activity 2. From activity 2 the same help file can be accessed through a link. If trainee is identified as expert on these competences, the submission of the activity A1 screen leads them directly to the activity A2 screen without displaying the help file. However, the help file would be accessible from activity A2 through a link.

This process can be extrapolated to all the activities defined along the CE process tool defined by V-CES as E-mentor.

5.5 Summary

This chapter details the way the framework described in chapter 4 has been implemented for the four core areas where intelligence has been brought: ‘suggestion of the CEM’, ‘suggestion of the e-training path’, ‘trainee as novice/expert’ and ‘tailoring the CE process’.

To identify the system requirements and make sure they have been captured, use-case diagrams were deployed. The actors interacting with the system and the actions to be undertaken by them were calculated. The fact of bringing intelligence to an existing structure implemented by the research of the framework (V-CES) implied some constraints but also the reusability of the functionalities.

The technologies selected have been the same as the research context defined (V-CES):

- Apache as External Web Server with database services
- MySQL as database server (RDBMS to support a VLE and a cost database)
- Moodle as VLE.
- Deployment of the presentation level: html, php and javascript languages.

The ‘suggestion of the CEM’ area is implemented before carrying out the CE process using the E-mentor proposed by V-CES. The access to it is voluntary and leads to the cost estimator selection of the CEM. The implementation consists of two screens. Screen one contains the form where information is requested in terms of stage of the project life cycle, and data and resources available. A rule-based system analyses the inputs and provides feedback regarding the suitability of the CEM in the second screen. In the same screen, the CEM to be carried out has to be selected by the cost estimator. This area was directly validated with 9 cost estimators.

The implementation of the other three areas is presented in this chapter, although the validation was carried out after defining a test scenario and a case study (presented in chapter 6).

‘The suggestion of the e-training path’ area requests the implementation of 2 major areas. The first area is the assessment of the trainee competences and the second area is the suggestion of the e-training path itself. The actions involved in this area were studied and worked out which can be re-used from the research context deployed within the VLE (Moodle) and integrated with the new developments. New developments consist of different screens to assess the current and target the level of competences (by evaluating the knowledge and skills possessed by the trainee) and a database (Assessment database) to store the inputs of the assessment and the e-courses suggested by the e-mentor.

The assessment of competences mentioned in the previous paragraph is leading to the definition of the ‘trainee as novice or expert’ at the competence and CEM level. The e-mentor queries the self-assessment (current) level attribute on the ‘Assessment database’ for the trainee in each competence. This enables the recognition as novice or expert at the competence level. In the test scenario, it is shown the way that the competences are clustered within the 3 CEMs: analogy, detailed and parametric. This is establishing the basis for further work when defining the trainee as a novice or expert for each CEM. Some criteria to set up the grades and weights for each of the competence within each cluster should be done.

The recognition of the expert or novice, at the competence and CEM level is opening many doors to apply different actions. The fourth area where intelligence has been applied is to address an action in terms of providing a ‘tailored the E-mentor’ (in terms of help). The activities along the CE process are linked to the related competences. E-mentor queries the novice/expert status of the competences related to the activity on the ‘Assessment database’ and automatically displays the help file if status is novice.

The following chapter defines a test scenario in order to validate the whole prototype within a real context in the field of Cost Estimating. Up to now, the validations presented in chapters 4 and 5 were done independently for each of the four areas where intelligence is applied. As the areas are linked to others, it was important to test the whole system and validate the link between the areas. Two case studies to validate the whole system were carried out. The first case study addresses the ‘suggestion of the CEM’ and the second case study targets the other three areas: ‘suggestion of the e-training path’, ‘trainee as novice and expert’ and ‘tailoring the CE process’.

6 Definition of Test Scenario and Prototype Validation

The previous chapter details the implementation of the framework proposed in chapter 4. User-cases were used to detail the requirements of the implementation and the various screens of the application are described. The implementation of the area ‘suggesting the CEM’ was validated.

The full completion of the framework, in terms of content, was not within the scope of this research. However, a test scenario has been defined in order to have a more accurate validation of the whole prototype (framework and implementation) within the discipline of Cost Estimation. The purpose was to develop a representative part of each key element in the framework.

The test scenario and the prototype validation are presented in this chapter. The validation of the prototype is completed by performing 2 case studies.

6.1 Definition of Test Scenario

A test scenario is defined in order to validate the framework and its implementation within the Cost Estimating discipline. The content of the framework is not an objective of the research, although two reasons justify the relevance of defining the test scenario for the prototype validation. First reason is to work out and experience the difficulties when carrying out the different tasks designed within the framework. Second reason is about being able to validate the framework in its real context (Cost Estimating).

The following elements have been developed in building up the test scenario for the prototype validation of the three areas of intelligence: ‘suggestion of e-training path’, ‘trainee as novice/expert’ and ‘tailoring the E-mentor’:

- List of competences based on the CE process.

- Set of knowledge, set of skills and test of knowledge for 3 competences:
  - Cost Estimating Relationships
  - Data Normalisation and Calibration
  - Learning curves
- Definitions of the table of content for the 3 e-training courses and link them to list of competences.
- Help files:
  - Data Normalisation
  - Breaking down the project
  - Estimate requirement definition (CARD)
- Exercise to normalise data.

6.1.1 List of Competences

The list of competences is not an objective of the research but it enabled to design the credible context where to deploy and validate the application. The driver when defining the list of competences has been the creation of cost estimates based on the CE process.

The list of competences is used in the two areas of intelligence:

1- Suggestion of the e-training path (section 4.4): Competences required for Cost Estimating.
2- Tailoring of the E-mentor (section: 4.6).

When defining the list of competences different issues were considered:

- Identification of main activities and requirements coming from the three CE process: analogy, detailed and parametric.
- Match which competences/skills/knowledge identified from the literature review. After the literature review, it was pointed out that only I.C.Grant's list has a specific emphasis on the CE process. Others are generic competences and not suitable with this thesis approach.
- Validate and get feedback from experts.

The CEM used when defining and validating the list of competences is presented in Figure 6-1:

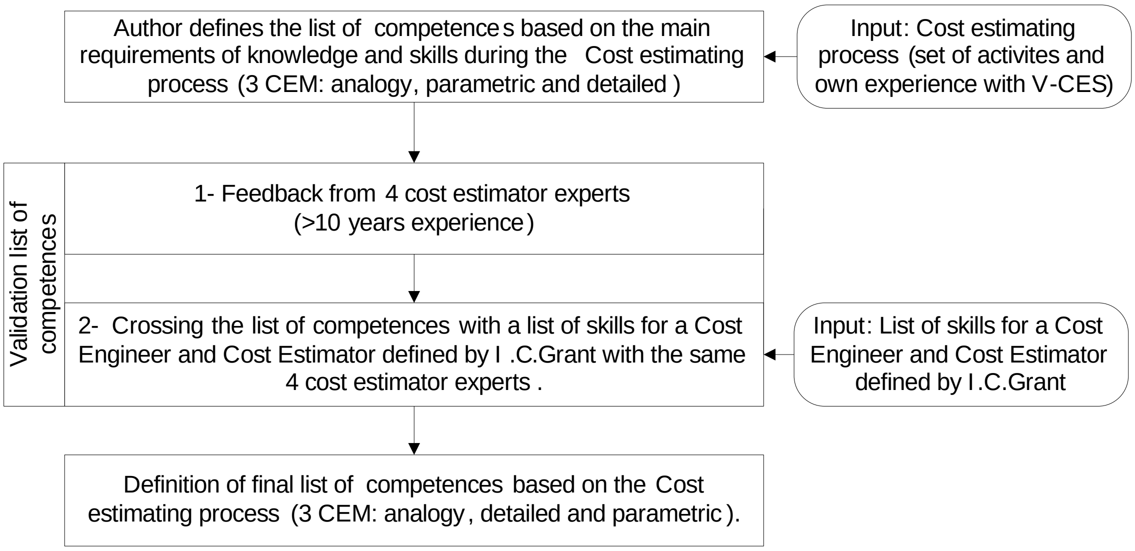


Figure 6-1 Methodology to define and validate the list of competences

The second step in the competence validation (see Figure 6-1), led to the definition of the questions 3 and 4 in the form 8 (see ANNEX B). This was done in the following way and for the exposed purposes.

Table 6-1 Sub-steps from step 2 presented in Figure 6-1 and its purpose

STEP	PURPOSE
2.1.- Go through the list of skills defined by I.C.Grant and match them with the competences selected in the authors list (author did a preliminary matching as a starting point in the validation process).	- Understand the list of skills defined by I.C.Grant. - Validate the thesis list in terms of deepness of the competences (not too much detailed nor too general). - Validate the list in terms of agreement between the competences selected in this thesis (regarding the Cost estimating process) and the list of skills for a Cost Engineer (and cluster for Cost Estimator) defined by I.C.Grant.
2.2.- Go through the list of skills defined by I.C.Grant again and focus on the skills not identified in authors' list and ask the question: "should they be included in the authors' list? Are them relevant enough when creating an estimate based on the cost estimating process (using the 3 methodologies)?"	- Make sure we do not miss any relevant concept , in terms of knowledge and skills required to undertake an estimate based on the cost estimating process , that should be present in the authors' list of competences.

After the first list of competences was defined and validated through the methodology presented in Table 6-1, a final list of competences was concluded (see Table 6-2). The validation of the results leaded to the final list (the process is detailed in questionnaire 9, see ANNEX C). Four cost estimating experts (users 1, 2, 3 and 12, see Table 3-1) were used to validate. The validation process consisted of individual semi-structured interviews followed by questionnaire 9 (see ANNEX B).

Table 6-2 Final list of competence based on the CE process

COMPETENCES (CE process)	
General	Concept of cost estimating **& terminology**
	Cost engineering/estimating methodologies
	Data normalisation and calibration
	Breaking down the project
	Documentation and data management
	Drawing and specification reading and analysis
	Industry and general manufacturing knowledge
	Estimate requirement definition (CARD)
	Learning curves (cost improvement slope)
	Basic mathematical, statistics & analytical skills
	User level in related software applications
	Basic Finance and accounting concepts
	Risk evaluation and analysis
	Audit
Detailed	Detailed process
	Data collection – (Material, Labour, Equipment)
	Product specific manufacturing process
	Detailed cost modelling
	Estimating allowances
Analogy	Analogy process
	Data collection (Design, Manufacturing, Cost, etc.) of strongly similar products.
	Development of cost factors
Parametric	Parametric process
	Definition of hypothesis
	Data collection of historical data (manufacturing, design, cost, etc.)
	Statistical analysis
	Cost Estimating Relationships
	Parametric cost modelling

Table 6-2 shows in bold, the changes added from the original list of competences, which are:

- Adding the word, “terminology to the competence”, to ”Concept of cost estimating”.
- New competences:
  - Documentation and data management
  - Industry and general manufacturing knowledge
  - Risk evaluation and analysis
  - Audit
  - Product specific manufacturing process
  - Estimating allowances

A difficutly when defining the competences was pointed out when limiting the number of competences to include. It was important to work next to the expert and to ensure the rememberance of the key driver: the CE process. It was easy to begin opening boundaries and adding new competences that are related but not directly requried (as for example: communication skills, green knowledge or rough order magnitude). Questions to readdress the interview were focused on:

- Is this a competence required to create a cost estimate and specifically required to undertake the CE process?
- Is this competence in a similar level of relevance to the other competences identified?

6.1.2 Competence Complete Description

In order to experience the system, the completed definition of the three competences: ‘Learning curve’, ‘Data Normalisation and Calibration’ and ‘Cost Estimating Relationship’ was completed. Three different cost estimating experts, using learning material from NASA, Parametric Cost Estimating Handbook, Rolls Royce and Airbus power point presentations, etc., defined the set of knowledge and skills as well as, the test of knowledge for the three competences selected. Each expert defined one competence. This allowed identifying the validity and limitations of using this approach in the research context: Cost estimating based on the CE process.

Table 6-3, Table 6-4 and Table 6-5 presents the set of knowledge and skills for the three competences selected.

Table 6-3 Set of knowledge and skills for the competence Learning Curves

Competence: **Learning curves**	
Knowledge (You know…)	**Skills** (You are able to…)
1- What are the contributing factors to learning and so cost reductions	1- Interpret historical data
2- The degree which different manufacturing processes are impacted by learning.	2- Recognise of trends and anomalies
3- Typical anomalies (description and how they are reflected in graphs)	3- Calculate historical line of best fit or identifying a possible LC that fits in your data.
4- Which is the peripheral knowledge (e.g. suppliers affecting learning curves)	4- Recognise the effects of peripheral knowledge
5- When to rely on learning curves	5- Apply learning curves
6- Types of learning curves.	
7- How to create learning curves	

Table 6-4 Set of knowledge and skills for the competence CER

Competence: **Cost Estimating Relationships (CER)**	
Knowledge (You know…)	**Skills** (You are able to…)
1- (about) CER development process.	1- Evaluate/interpret from data the relation between cost drivers and cost defined in the hypothesis and other missed in them.
2- Techniques (types) for developing and implementing CERs.	2- Ability to use Least-Square Best Fit (LSBF) techniques to derive CERs.
3- Limitations, errors and caveats of the use of LSBF and graphic method techniques.	3- Ability to use the graphical method to derive CERs.
4- When to use CER: strengths and weaknesses.	4- Generate linear and non-linear relationships.
5- What has to be considered to validate a CER.	5- Read and interpret graphics.
	6- Identify engineering solutions, determine a possible relationship around which data can be gathered and relationships determined.
	7- Conduct significance testing.
	8- Justify the validity of the CER selected.

Table 6-5 Set of knowledge and skills for the competence Data Normalisation and Calibration

Competence: **Data normalisation and calibration**	
Knowledge (You know…)	**Skills** (You are able to…)
1- (the) Purpose to normalise data. Problems with raw data.	1- Apply **inflation rates** to the historical data to use.
2- (the) Ways you normalise data.	2- Apply **currency exchanges** to the historical data.
3- (the) Purpose of calibration.	3- Apply **production rates** to the historical data.
4- (the) Achievements with calibration.	4- Model the Theoretical First Piece (T1) to eliminate the **quantity affect**. This is achieved by eliminating the Cost Improvement Curve effect.
	5- Separate **non-recurring** and **recurring costs** to the historical data.
	6- Adjust for **consistent scope.**
	7- Adjust for **anomalies**.
	8- Able to identify the companies technologies were a productivity advantage is evident.
	9- Able to identify third party productivity through supplier assessments.
	10- Able to manipulate the commercial model to reflect historical experience of the organisation regarding **Products.**
	11- Able to manipulate the commercial model to reflect accounting practices and **organisational** structure of the company.
	12- Use a calibrating tool.

The definition of the set of knowledge and skills was pointed out as one of the difficult points within the definition of the framework content. Issues which require a special consideration are presented:

- "Knowledge and skills have to be the ones required for the competence in general or which can be trained/offered by the web-based system?"
    - o The list of knowledge and skills has to be defined independently of the web-based system restrictions. The e-training path offered by this research is e-courses, but in the future it could be extended to other practices such as attending conferences. However, it is important to keep in mind the idea that the knowledge and skills

are requested to be able to carry out an estimate based on understanding and using CE process.

- “Has this requirement for the competence to be considered as knowledge or skill?”
    - o This question was addressed in the following way: if it implies the real action of performing the competence it will be skill, but if it is more related with the acquisition of understanding through studying then it will be knowledge.

The creation of the test was completed following the principles described in the framework:

- Number of questions: between 5 and 10.
- Each question has to address one or many sets of knowledge.
- Each set of knowledge has to be referred at list in one question.

Previous guidelines make the task of creating the test easier and less crucial than the definition of the set of knowledge and skills, if they are well defined. The knowledge tests, as well as the relationship between the questions and the set of knowledge, for each of the three competences, are enclosed in ANNEX I.

An interesting issue pointed out was that some of the questions defined for the knowledge test were testing skills and not just knowledge. An example could be to request to apply inflation rates. However, as presented in the following chapter discussion, questions where this issue was identified, knowledge was also tested apart from the skills.

6.1.3 E-training Courses

Another key element for the suggestion of the e-training path is the definition of the e-training courses. As explained in section 4.5.3, the role of the mentor/teacher is to define the content of the e-training course. As the application (V-CES) is not fully operating, no e-training courses were defined in the area of Cost Estimating from the mentors/teachers. In order to define this element within the test scenario, trying to be as objective as possible, the table of content was selected from existing courses found in literature targeting the Cost Estimating discipline. The course content and its relation with the list of competences are presented in ANNEX K.

6.1.4 Relation Activities – Competences and Help File Document

The activities implemented by the research and the competences linked to them are presented in Table 6-6.

Table 6-6 Relation between activities and competences implemented

ACTIVITY	COMPETENCE
A2: Define the Work Breakdown Structure	Breaking down the project
A3: Create Cost Analysis Requirements description (CARD)	Estimate requirement definition (CARD)
A6 Data Normalisation (implemented in parametric)	Data normalisation and calibration

The author defined; the relationship between the activities and competences, and the help file content from reliable sources of information such as NASA Cost Estimating Handbook and the ISPA/SCEA Parametric Cost Estimating. There is 1 help file for each competence. The implementation of the system would expect a cost estimator expert (see Figure 5-9) to carry out this action, but the approach is suitable enough to validate this area of intelligence. Awareness of needing to improve the content of the help file is identified and considered for future work.

6.1.5 Exercise for Validation

The exercise has been used to validate the area of tailoring the E-mentor tool as a CE process. It focuses on developing the activity, ‘Normalisation of data’, as a main activity on any of the 3 CEMs: analogy, detailed and parametric.

Some raw data was provided (see questionnaire 7, ANNEX B) and the trainee was requested to ‘Normalise’ it.

6.2 Final Validation of the Prototype

The final validation of the prototype was completed through 2 case studies. Case study 1 validated the prototype using the test scenario. This involved the three areas of intelligence: ‘suggestion of e-training path’, ‘trainee as Novice or Expert’ and ‘tailoring the CE-mentor’; as they are related to each other. The information required or obtained in one area is used in the others. Case study 2 covered the use of the application to ‘suggest the CEM’ along with a complete project life cycle project of a Wing Box Ribs. This area is not directly linked to the others, so another type of case study better fulfilled its validation.

6.2.1 Case study 1: Implementation Test Scenario

The process to validate the prototype with the test scenario was carried out with the three cost estimators: users 9, 11 and 12 (see Table 3-1). The process consisted of the following (see detailed in ANNEX B, questionnaire 7):

1- User was requested to do the assessment of competences. The competence, ‘Data Normalisation and Calibration’, was assessed using the complete system assessment: set of knowledge and skills and the knowledge test. The rest of the competences were assessed manually with the possibility to use the system assessment for the competences: ‘Learning curves’ and ‘Cost Estimating Relationship’ (ANNEX B, questionnaire 7, part 1).

2- The user was presented a situation where the data had to be normalised (ANNEX B, questionnaire 7, part 2).

The user was logged into the system (E-mentor tool) and was directed to the previous activity to: ‘Data Normalisation’. If they were considered as novice in the competence, 'Data Normalisation and Calibration', a help file window was automatically displayed before the activity of Data normalisation. During the activity of normalising data, either considered novice or expert, a link to the same help file was available.

The purpose of this validation was to evaluate the integration of the whole system (apart from the 'suggestion of the CEM') and see how cost estimators fell in going through the process. The results are presented in Table 6-7.

Particularly objectives were the following:

1- Validate the assessment of competences approach.
2- Objectively evaluate the trainee as novice or expert in the competence 'Data Normalisation and Calibration'.
3- Help file displayed is appreciated by the novice.

Table 6-7 Result from the case study 1 and questionnaire 7 from ANNEX C

User		User 9	User 11	User 12
Data Normalisation Level				
	Self-assessment	1	1	2
	Target	4	2	3
% of knowledge		Not answered	3/4= 75%	3/4= 75%
Knowledge test		4.33/10	3/10	10/10
% of skills		7/12= 58.3%	3/15= 25%	7/12= 58.3%
Novice/expert		Novice 1	Novice 1	Novice 2
Did you manage to carry out the assessment?		Yes	Yes	Yes
Did you come across to any difficulty?		Yes. Did not understand the meaning of 2 skills and 1 question from the test	Yes. Some of the set of knowledge and skills, and some questions on the test were not clear	Yes. He did not understand 1 set of knowledge. He though the target was related to his job and not to his own interests.
Did you find the knowledge test difficult?		No	No	No

User	User 9	User 11	User 12
Do you like the way of listing the courses?	Yes	Yes	Yes
Comfortable with Excel	Yes	Yes	Yes
Normalisation types	Inflation, different num of engines, technology improvement, different length, currency, mass and max range.	Anomalies, Inflation, learning curve, different num of engines, currency.	Anomalies, Inflation, learning curve, technology improvement, currency.
Automatically help file displayed	Yes	Yes	Yes
Did you appreciate to receive the help file before the activity?	Yes	Yes	Yes, but having the link during the activity was enough
Use the help file meanwhile the activity?	Yes (for LC and consistent scope)	Yes (LC)	Yes (Production rate and LC. He works using tables for LC, he had to review the formula)
Could you have done the activity without the help file	No	No	No

An interesting comment pointed out during the validation process from user 11 (related with applying inflation rates) was the following:

- "Do you mean the skills I think I have or the skills I think I have because I have got experience on them? I have never applied inflation rates but I still think I can do it. If I have to hammer a wall, I have the skill to handle a hammer, to crash, etc., but perhaps I have never done it".

The answer to that was that the system expects to answer the skills you think you have but you have had to experience them. This is because it may arise that you may have experienced similar actions but not done together, in the same order, with the same object, etc.

Discussion of the results based on the three objectives is presented as following:

1- *Validate the assessment of competences approach*.

Even if the approach had been validated in the framework, there were some questions testing the validity that were difficult to be assessed in the framework status. The three participants managed to carry out the assessment and the way of listing the courses was considered as a good way.

2- *Evaluation of novice/expert*:

User 9 and 11 were expected to be considered novice 1 or 2 due to the years of experience and the lack of practice in Normalising data.

User 12 was expected to be expert 1 or 2 because of the amount of years experience and he explicitly mentioned many years of experience in normalising data. The system did not recognise it for the following reason:

- He did not understand the fourth set of knowledge answering he did not possess it. This led to have 75% of the knowledge. Even if the test was 100% correct, the system took the lower value. To be considered as an expert the knowledge required has to be above 90%.

Possible actions to undertake:

- Review the limits of knowledge and skills. Change % of knowledge for level 2 at superior or equal 75%.
- Prioritize the test. If user undertakes the test use this value even the set of knowledge is considered.
- Better explain the set of knowledge and skills including examples into brackets.

3- Help file displayed is appreciated by the novice.

The three users were recognised as novices and they answered the help file was useful and required to accomplish the activity. The fact that user 12, which should have been recognised as an expert mentioned that there was no need to display it before the activity, as the link can be accessed during the screen to normalise the data is a good insight of the approach, though more users should be tested before any definitive conclusion.

6.2.2 Case Study 2: Project Life Cycle Wing Box Ribs

The validation of the 'suggestion of the CEM' area where to bring intelligence was done in chapter 4.4.3 where eight cost estimators did the exercise to think of real examples they had to estimate and test them using the system implemented by this research.

Using the same criteria of crossing real examples with the system implemented, a case study was defined: 'Project Life Cycle Wing Box Ribs' by User 1 (see ANNEX A). This was a real project with a budget order of £259k and approximate duration of 3 years. The analysis of the project was done in the following way:

1- Identify the project in the 3 stages of the project life cycle: preliminary, intermediate and final. The definition of the percentage of project definition and an approximate accuracy were defined.

Per each of the 3 stages the following process was done:

a. Define characteristics of the stage in terms of data and resources available.
b. Methodology/ies used to carry out the cost estimation.
c. Outcome or use of the cost estimate.
d. Answers of the questions in the form to suggest the CEM.
e. Extraction of the feedback/suggestion proposed by the e-mentor.
f. Choice. This means which action would you undertake after reading the feedback?
g. Duration of doing the cost estimate.

Results of the case study are collected in ANNEX G. The implementation of the 'suggestion of the CEM' was successfully validated as:

1- All questions in the form were meaningful according to the correct description in each of the stages along the project life cycle.

2- The e-mentor feedback agreed with the CEMs used to carry out the cost estimation. The explanations were considered didactic and helpful according to User 1.

6.3 Summary

The test scenario has been a key development to validate the feasibility of the approach and work out the difficulties when developing the content of the framework and using the application within the Cost Estimating discipline.

The development of the framework content within the area of 'suggestion of the e-training path' has been identified as a tricky part which demands a lot of effort and collaboration. The completion of the content framework was not within the scope of the research, but the definition of the test scenario has enabled to give a flavour on the various elements involved.

The definition of the list of competences was done using reliable literature; Cost Estimating Handbook (NASA) and Parametric Estimating Handbook (ISPA/SCEA), a list of competences for a Cost Engineer rigorously set up (I.C.Grant) and the validation feedback from four cost estimators with more than 10 years experience in the area of Cost Estimating. The difficulty found out was where to stop including new competences. The criteria to cope with this was to identify if the competence was as relevant as other competences included in the list and directly required when carrying out the CE process based on the 3 CEMs: analogy, detailed and parametric.

The definition of knowledge, skills and the knowledge test was done with 3 cost estimator experts (each one defined it for one competence) with input from different literature. The tricky points were:

1- Knowledge and skills should be the ones for the competence without thinking at this stage if they can be trained or not by the system. The e-training path offered in this thesis is e-courses but in a future could be extended to other practices (such as attending conferences) or other training tools.

2- Establish boundary of what is knowledge and skills.

3- It was realised that few questions defined where targeting skills. As those questions implied the understanding of knowledge they were not modified.

The extrapolation of the test scenario to the creation of the content of the application within the areas: 'suggestion of the e-training path', 'trainee as a novice or expert' and 'tailoring the E-mentor' could not be done directly. The Cost estimating community, seen as workshops with experienced cost estimators from both industry and academia or organisations such as ACostE should define the content in terms of set of knowledge and skills, test of knowledge, help files and link the activities with the competences.

7 Discussion, Future Research and Conclusions

The previous chapter defined a test scenario and two case studies to validate the approach and implementation of bringing guidance and support within the Cost Estimating discipline.

This chapter discusses the findings of the research, the contribution to knowledge, the limitations and future research. The four main areas where intelligence has been deployed are discussed independently. Conclusions are stated in relation to the objectives defined at the beginning of the thesis.

7.1 Findings of the Research

This section is targeting the main results achieved by this research against the objectives outlined in chapter 3.

7.1.1 Review of Literature

The literature review points out that there is a lack of training in the area of Cost Estimating. Different online training courses related with Cost Estimating have been found from organisations such as SCEA, NASA or DoD and academic institutions such as *Iowa State University*. However, none of them deploys an intelligent e-mentoring platform focused on the CE process which:

1- Propose a tool to suggest the suitable CEM according to the varying requirements.
2- Assess the level of competences in the area of Cost Estimating with an objective assessment based on knowledge and skills.
3- Propose the e-training path focusing on the trainee needs and interests.
4- Recognise the user as novice or expert and tailor help within a CE process tool. This tool, the main part of the research context (V-CES),

has already been an innovative service within the area of Cost Estimating.

7.1.2 Suggestion of the Cost Estimating Methodology

From the literature review, the main factors that influence the CEM to be used have been identified (see Table 4-1). On a generic basis, literature agrees in using; parametric and analogy based methodologies in the early stages of the project lifecycle when the project definition is limited, and using detailed methodology in the later stages of the project life cycle when the project definition is advanced.

A generic theoretical criterion for the selection of suitable cost estimating methods was found in literature. However, there is no system found in literature in which the user, by being requested some specific information, is given the most suitable suggested CEM. The reasons of its absence may be explained due to the difficulty to be more specific in the recommendation criteria and still providing generic rules independently on the sector, company or product; and the fact that most of the software tools make use of a single cost model which can be built up with one or more CEMs (the use of a particular software tool determines the CEMs to use).

The motivation of bringing intelligence in the suggestion comes from two different areas:

1- Training purpose: guide the cost estimator when selecting the CEM according to the project context.
2- Disallow the cost estimator in beginning an estimate without being able to provide main resources and the required data for the CEM. This issue was pointed out thanks to the contact with cost estimators during the development of the research context (V-CES) when attempting to perform an estimate using a CEM that they were not familiar with.

Due to the training aspects and understanding of the requirements of each of the three CEMs, an intelligent tool has been developed providing feedback on the suggestion of the CEM. The main factors identified in literature (see Table 4-1) are broken down into specific needs to build the requests of the form. The form is the interface where the characteristics of the cost estimate are entered. The feedback goes further than just naming the suitable CEMs. It also:

- Justifies why a CEM is not suitable and what is required in order to make it suitable.
- Recommends to the user to perform many suitable estimates according to the case to cross check and be more confident about the result.
- If a ‘detailed’ estimate is an option and you are not able to get all labour, machine or material data then data available in the V-CES database will be provided.
- If you are in the Intermediate or Final stage, bear in mind the cost estimation you may have done in previous stages.
- If you have many options, establish some high level criteria for the selection. The criteria will consider factors like: time to do it and accuracy required.

The framework and implementation was validated with 8 cost estimators and a case study (Project life cycle wing box ribs) to cross reference the application with a real project.

The form which requires inputs to describe the CE situation basically addresses information of the project life cycle stage, and the data and available resources. It has been possible to present these generic requirements in a more specific way. The type of data and resources required and the description of the project life cycle stages have been defined with a reasonable and representative number of questions.

The integration of time and budget resources as a direct input in the form was considered interesting by cost estimators. However, it was decided to not include them for two reasons:

1- To include these 2 variables a major study should be undertaken analysing a representative amount of real projects.
2- For training purposes it remains reasonable to consider it in a non-quantitative way in the feedback.

The approach to describe the project life cycle proposed by AACE (2004) has been used and adapted to meet the manufacturing sector (especially aerospace, automotive and semi-conductor equipment) and the characteristics of the V-CES project. Every cost estimator was familiar with the terms for the project life cycle: Preliminary, Intermediate and Final, but different ideas were built on it when describing the percentage of project definition, accuracy and end purpose. For this reason, it was important to keep the variables that are describing each of the three stages and not implement it as a help option. For instance, if the cost estimator had the idea that 50% of project definition was at Intermediate stage, they should answer the form by saying Final (if the rest of the variables also points in the same direction) to be consistent with the approach. An exercise trying to set up the accuracies range was done with 7 cost estimators. Different answers were given by even cost estimators who belong to the same sector and company. However, as they were quite close to the initial range proposed by ANSI, it helped to validate the accuracies considered.

The validation of the form has been done in both the framework and the implementation stages. It was pointed out that it is much easy to validate the content of the form in the implementation stage as the user can accomplish the whole process of the system by receiving the feedback and reviewing the inputs. The content of the input (form) is related with a flexible feedback.

The e-mentor feedback was considered really useful from the cost estimators validation as it not just suggests the appropriate Cost Estimating Methodology/ies, but it also explains the reasons, provides criteria to make up cost estimator’s mind and the data when requested.

The case study of the “Project life cycle of the wing box ribs” proved the validity of the approach in terms of describing a whole real project life cycle and agreeing with the CEMs to use.

7.1.3 Suggestion of the E-training Path

The suggestion of the e-training path refers to the steps to be carried out in order to improve competences in the CE area. This research approaches the suggestion based on available online courses offered within the research context service (V-CES).

In order to suggest the most suitable online courses it is necessary to assess the capabilities and interests of the trainee in an objective way. This has been approached by assessing the current level on competences and the target level (what is desired to improve). Competences in this thesis are compounded by knowledge and skills, and not attitude. Tacit knowledge is also not included. The key driver to evaluate the level on each competence is the differentiation and assessment of knowledge and skills. The acquisition of knowledge (as understanding of information) and skills (as ability to carry out a particular task or job) demands the user to use different training methods. They have been identified and adapted to fit into the research approach.

The approach was validated with 18 interviewed cost estimators, experts and novices. The results showed its validity in terms of differentiating knowledge from skills, assessing the knowledge through a test and the use of a software based environment to carry out the assessment.

In order to validate the framework within the study a test scenario has been defined, which includes:

- Definition of a list of competences required to carry out the CE process based on the 3 CEMs: analogy, detailed and parametric. The creation of the list has been done using the reviewed literature and 4 cost estimating experts.
- Definition of the complete system assessment (definition of set of knowledge, skills and test of knowledge) to automatically obtain the level on a competence for 3 of the competences: ‘Learning Curves’, ‘Data Normalisation and Calibration’, and ‘Cost Estimating Relationships’. This has been done using the reviewed literature and 3 CE experts.
- Definition of three online courses using their table of content from different organisations and universities. These courses were matched with the list of competences.

The validation of the prototype was completed using a case study based on the implementation of the test scenario. Three cost estimators were approached and interviewed, two with less than 3 years of experience and one with more than 10 years experience.

The definition of knowledge and skills followed by this thesis has been the key driver when defining the method to assess the level of competences and the training material to provide. To have skills does not always imply to have the knowledge, but a key assumption as a good learning practice has been the need to have the knowledge before training and applying the skills. For instance, before using statistical tools (skill) it is important to understand the statistical concepts such as standard deviation or normal distribution (knowledge). It is important to do it in this order; otherwise, if the context where to apply the skills is modified (e.g. result is wrong), it will be difficult to recognise which is the cause. If you have the skill but not the knowledge, the system first proposes the user to obtain the knowledge.

In order to be more objective when assessing the knowledge, a test is defined. It is expected to check what the user knows and not just rely on what they think they know. No test is defined for the skills as the online environment does not enable to show ability and assess the majority of the skills required. Boundaries when assessing knowledge and skills can sometimes be a bit fuzzy. It was also discovered that few of the questions defined in the test were actually assessing skills as well. For instance, the questions of applying currency exchanges or inflation rates assess skills, but the knowledge as understanding of what the currency exchange and inflation rates are and aimed for is also assessed.

The definition of the set of knowledge and skills and the questions on the test has been identified as a task to give special care. During the validation some were identified as not being understandable from the interviews. A special risk when defining and writing down these elements was identified as contingencies of the approach, though another interesting explanation has been found. Some comments stating that the sentence was not comprehensible were actually because of the fact that the cost estimator did not know the answer or not knowing the meaning of some words.

The experience itself is not directly addressed in the assessment, but takes a relevant role when assessing the skills. In the validation of the prototype the following was pointed out:

- Skills in this study demands to possess the ability and it demands to have had some experience in it. It does not work to conclude you have the skill because you possess the knowledge and similar abilities.

Knowledge and skills should be the ones for the competence without thinking at this stage if they can be trained or not by the system. The e-training path offered in this thesis is e-courses but in future this could be extended to other practices (such as attending lectures) or other training tools. However, it is important to keep in mind that the knowledge and skills are requested to be able to carry out an estimate based on understanding and using the CE process.

7.1.4 Trainee as a Novice or Expert

There is little written about the consideration of novice/expert within Cost Engineering and Cost Estimation disciplines. Thanks to the assessment of competences, this study defines a system to consider the Cost Estimator as novice and expert for each competence. Competences are defined to target the CE process for the 3 CEMs: analogy, detailed and parametric, and grouped in four clusters: general, detailed, analogy and parametric.

Due to this grouping it is possible to establish another classification of novice/expert at the methodology level. This is interesting for 2 reasons:

- Cost Estimators with relevant years of experience (more than 10 years of experience) in the Cost Estimating area may be expert in one methodology and novice in another (see ANNEX A).
- This may lead to new areas for intelligence. Some actions could be decided when presenting the E-mentor tool proposed by the research context (CE process) at the methodology level. The information could be presented in different screens or displayed differently.

7.1.5 Tailoring the E-mentor (CE Process)

The key driver when developing the research has been to help the cost estimator to develop cost estimates based on the CE process. This led to the definition of competences to meet the purpose.

Activities to carry out during the CE process presented by the E-mentor (implemented within V-CES) can be matched with the list of competences. It is possible to identify a particular activity which competences are related to it. As competences would have been assessed it is possible to know if the trainee is novice or expert on them. The intelligence approach is utilised when displaying the help files associated with the competences that are related with the activity. The pop up help files will appear just before the activity commences.

7.2 Research Contribution

This research has significantly contributed in defining and implementing a second level of e-mentoring within the research context. The first level was established by the research context (V-CES) which the “step by step” tool which guides the trainee along the different steps to carry out a cost estimate. This second level can be called intelligent as the system identifies patterns regarding the cost estimator and the project situation and responds at it offering guidance and support.

The literature review identifies the main factors that influence the CEM selection but there is no system which suggests the CEM after being requested some information. This research study has implemented such a system.

The system consists of an online form to receive inputs to describe the CE situation. It addresses information of the project life cycle stage, and the data and resources available. It has been possible to present these generic needs in a more specific way due to the understanding of the requirements of the CEM. The type of data and resources required and the description of the project life cycle stages has been defined with a reasonable and representative number of questions.

A rule-based system analyses the answers and provides feedback regarding the suggestion of the suitable CEM. This feedback goes further than just mention the appropriate CEM; it also provides explanations about the criteria, gives recommendation and proposes data available from the research context (V-CES) development when required.

Alternative methods would include reading books where the main factors to select the CEM are mentioned and move to understand how these general factors are applied to each of the CEM. This process can be a bit complex as many issues have to be considered and related. The use of this system provides efficiency in deciding the CEM, accuracy in the selection to avoid personal bias or preference on the use of any particular CEM and easy understanding of the criteria of the selection.

Competency-based applications have been developed for many years. Some applications define the competences required for a cost engineer and cost estimator but few of them really focus on the CE process and the training aspects. The competence-based approach done in this thesis is focused on providing the suitable e-training material. This is why the assessment differentiates knowledge from skills as it has been recognised that different training techniques addresses them. The way the system has been designed and implemented is genuine in its global format as the independent elements can be found separately in other applications and disciplines.

This competency-based system assessment has led to provide a classification system of the cost estimator as novice or expert. A specific contribution to knowledge is the suggestion of the e-training path. The way to look for e-training courses in the area of Cost Estimating it is mostly done by either reading the list of available courses and to decide which better meet the user interests or, by entering key words in a browser and getting the list of courses which contains them. No system has been found to propose the courses that match the user needs and interests using a competency-based assessment in the area of Cost Estimating. The potential of the approach is the possibility to extend this e-training path to the proposal of other resources apart from the e-courses.

Considering the E-mentor tool implemented by the research within V-CES as a contribution to knowledge itself, the fact of adding the attribute to tailor help when required is also a contributing factor.

7.3 Limitations with the Research

There are mainly two sources of limitations; coming from the solutions proposed by the thesis and from the research itself.

Limitations from the area of 'suggesting the CEM' are coming from the boundaries of the research scope and the framework (and its implementation). Different items have been identified as being out of the scope of the project due to limitation of time and resources; and constraints from the project context (V-CES).

When 'suggesting the CEM', schedule (time available) and budget have not been considered as inputs as it would demand a much deeper study on these variables (the analysis of different real projects should be done), though the e-mentor feedback addresses the time variable in a non-numeric way. The implication of this in terms of training is acceptable as the application provides a useful and relevant feedback.

Some limitations are also seen in terms of validating the intelligent e-mentoring developments in the areas of 'suggesting the e-training path' and 'tailoring the E-mentor (CE process)'. The objectives of this research were coming from the identification of these areas as interesting ways to bring intelligence to the system, the proposal of the framework as the way the system will operate and its implementation. Author does believe that the framework provided in both cases could be applied in other disciplines. The fact of giving the context and therefore the particular content in Cost Estimating was a need in order to validate the prototype. Even if the development of the content (knowledge, skills, knowledge test, help files, etc.) was out of the scope of the study, the definition of the test scenario aimed to define a representative content of each of the key elements of the framework. However, the final development of the framework content (set of knowledge, set of skills, test of knowledge, e-course content and help file content) should be improved in comparison to the test scenario. The roles defined by the framework should be followed and more CE expertise inputs should be included.

For the assessment of the competences, more help, a user manual and a description for each of the competences, should be viewed when fully developing the area of ‘suggesting the e-training path’.

In survey terms, the limitation to gain access to professionals to validate the various areas of development is pointed out. However, within the project time resources, the relevance of the sample community contacted has been a success. Bias from the author and organisations’ individuals due to its own experience and contact within the research context project may be seen. Author experience can be also viewed as an added value to a better understanding of the requirements and limitations. Some parameters and names (ex. end usages in project lifecycle) are subject to individual experience due to particular sector, company and own professional background. Bias has been mitigated by performing triangulation using various well recognised sources of data gathering (Robson, 2002) and by validating the inputs from CE experts with recognised sources of information.

This research targets the ‘manufacturing’ sector, as well as V-CES does. The fact that most of the participants were from the aerospace, automotive, and semi-conductor equipment sectors may be viewed as a source of bias. This is addressed by V-CES with disseminating and assessing European activities where variety of sectors participated.

The subjectivity from the user when answering the test of knowledge and the set of knowledge and skills has been identified as a risk that should be addressed by educating and explaining accurately to the user the aim, methodology and benefits of using the system in a particular way.

7.4 Areas of Future Research

The detection of the limitations can be minimised through future research and development of this work. The main improvements and developments for each of the four areas where intelligence has been implemented and a final section with new areas are suggested in the following sections.

7.4.1 New Areas in Suggestion of the CEM

The integration of time and budget as direct inputs in the form will provide a complete view on the parameters that influence the selection of the CEM. It will demand a fully study of experimental case studies as not a lot of literature is available in this, but if generic results are calculated, it will be beneficial for the application.

In reality companies may perform estimates using a combination of various CEMs. After some research in how to combine the CEMs and the implementation of a tool which addresses the task, the suggestion of mixed CEMs can be incorporated. This issue is perceived interesting from the cost estimator domain.

7.4.2 New Areas in Suggestion of the E-training Path

The inclusion of experience and certifications to the competency assessment could be considered as a check against the results obtained from the assessment of knowledge and skills.

The test scenario was the first approach to develop the content of the framework. The set of knowledge and skills, as the test of knowledge within the test scenario, should be reviewed with more CE experts before considering it as the final version, and then extended to the rest of the competences.

An automatic update of the level of competences should be provided to avoid the user in performing the assessment each time the e-training path is desired.

The update could be done after doing the e-courses if successful. Another updating method could be completed after carrying out a cost estimate using the system e-mentor (V-CES), though feedback and access to the process should be done to assess its correctness.

An extension of the e-training path can be achieved, by adding other resources as conferences or books, apart from the e-courses. It will give to the application a fully genuine type of content not seen in the literature reviewed. This issue can be challenging when accessing, controlling and updating all new resources.

The system should need regular maintenance to update the system with new competences, knowledge, skills and test of knowledge. It will be required a full time job performing the role of administrator, to keep the system up to date, will be required.

7.4.3 New Areas in Trainees as Novice/Expert

The main area of future research comes from the implementation of considering the trainee novice or expert for each of the 3 CEMs: analogy, detailed and parametric. A system to decide the weight that each competence within the cluster has, regarding how relevant it is within each CEM to consider, should be done. A first approach could be: if you are considered as an expert in all the competences contained in the general and CEM x (being x: analogy, detailed or parametric) clusters, then you will be an expert in the CEM x. Otherwise, you will be a novice in CEM x. For instance, to be considered as an expert (or keeping the classification of expert 1 and expert 2) for the analogy methodology, you should have level 3 or 4 in all the competences contained in the clusters: “general” and “analogy”. This method has been seen as inaccurate after the feedback from Cost Estimation experts, as competences do not have the same relevance, difficulty and frequency.

The consideration of novice and expert could also include the first time you use the system.

7.4.4 New Areas in Tailoring the E-mentor (CE Process)

The tailoring help process is done for the two generic classes: novice and expert. Help could be provided differently making use of the 4 classification levels: novice1, novice 2, expert 1 and expert 2.

The high level of approach is “Training by doing”, in which the trainee is entering information through different screens. This will enable the evaluation of the inputs during the CE process. This could provide some hints on when the user requires assistance.

With the recognition of the trainee as novice or expert at the methodology level, some actions could be undertaken. For instance, the application (E-mentor tool) can be implemented in different steps (screens) when requesting the data according the trainee being novice/expert. As seen from expertise recommendations, an expert will not require as many screens as a novice.

7.4.5 Other Areas where to Bring Intelligence

Many areas can be found where to bring intelligence. Two of them are presented in this sub-section as following:

- Making use of the data entered in previous cost estimates.
- Carry out a study on how attitude and pedagogy should be targeted.

7.5 Business Impact Analysis

The technical architecture for implementation purposes does not demand any change in respect of the resources required for V-CES project. These resources are detailed in a Business Plan defined by V-CES Consortium D.6.6 (2006).

The additional resources related with the maintenance of the system in terms of updating and/or adding new content on this research study. An extra person (in respect to V-CES plan) with an administrator role is estimated to be required to update and enter to the system:

- Competences, set of knowledge and skills and test of knowledge (through Moodle and Assessment database).
- Creation of the help files (having its content) and relating the activities within the E-mentor tool with the competences. In this research this has been done by coding it directly. An interface should be created to facilitate the task to the administrator.

The administrator will get all the information required to fill the implementation of the system (competence name and description, set of knowledge and skills names, the questions and answers on the test, the help files, the relation between activities and competences, etc., as defined along the thesis), which will have to be defined by:

- The CE community expertise. This is basically the role of the cost estimator expert described in sections 5.2 and 5.4. An example of the CE community could be organisations such as ACostE contributing to the content development.

The main benefits of the research are coming from a better understanding of the trainee cost estimator needs and guidance through the various services offered by the V-CES project. The cost estimator gain better understanding of the CE process by selecting the most suitable CEM and receiving help when required along the CE process. The suggestion of the e-courses will help them in deciding which course to enrol on. This research is contributing to the improvement of knowledge and skills within the Cost Estimating discipline and the framework implemented within the V-CES services.

7.6 Conclusions

This section aims to address the aims and objectives of the study presented in chapter 3 and in turn discus how each one has met with the thesis. The research has successfully achieved all the original objectives and has therefore met the original aim.

The research questions have been successfully answered as following:

- *Why intelligence is required for the cost estimating e-mentor?*

  Section 4.2 responds to this question. The research context (V-CES) provides two types of services: an E-mentor tool (‘step by step’ guidance along the CE process) and a platform where e-training material is available. With the purpose to help cost estimators developing cost estimates, knowledge and skills can be trained by offering more guidance and support when using and understanding these 2 core services.

- *In what could intelligence be incorporated within the e-mentor?*

  Understanding the GAP in the research framework (adding new attributes to the service) and validating it within the literature review has led to the definition of four main areas where intelligence has been incorporated. The four areas, as described along the thesis are:

  - Suggestion of the Cost Estimating Methodology.
  - Suggestion of the e-training path.
  - Trainee as a Novice or Expert.
  - Tailoring the E-mentor

- *What is the nature of intelligence required?*

  The nature of the intelligence used in this research is based on a production-based system which aims to provide guidance and support regarding cost estimating practices.

The first objective was to suggest the effective Cost Estimating Methodology/ies to be used by the trainee, referring to the 3 CEMs considered in the project: Analogy, Detailed and Parametric. It has been successfully carried out and validated with reliable literature review and the CE expertise.

The following elements are concluded:

- o From the literature review it has been pointed out that there is no intelligent tool to evaluate the suitability of the CEMs with the characteristics and resources of the CE situation.
- o General factors such as data or resources that influence the CEM selection can be more specifically defined to target the three CEMs: Analogy, Detailed and Parametric, with a relevant and reasonable number of questions.
- o The inputs to evaluate the project characteristics, after being recognised from the literature review and CE expertise, are collected through an on-line form.
- o The evaluation of the inputs in the on-line form is leading the e-mentor to suggest the suitable CEM with appropriate feedback regarding training purposes.
- o Both novices and experts within the CE discipline have identified this area of guidance as useful and helpful.
- o A complete project life cycle case study has been estimated using the application with successful results.

The second objective, provide guidance in the e-training path needed by the user, has been achieved by assessing the trainee competences and interests and suggesting the online courses available. The following statements conclude the meeting of the objective:

- o It has been identified from the literature review that there is no online system providing a tailored e-training path according to user interests in Cost Estimating. An outcome from the thesis is the suggestion of the e-training path by listing the suitable e-courses within the research content (V-CES) in a prioritised way.

- o An online form has been used to assess the trainee needs and interests by identifying current and target competences. Current competences were identified through a system assessment based on knowledge and skills.
- o The system assessment of knowledge and skills has been viewed as a reliable and objective method, but the creation of its content has been identified as a challenging task.
- o A system proposing suitable e-learning (and e-training) material has been defined by; identifying the trainee interests, the gap between current and target level of competences and the training material addressing them.
- o Both novices and experts within the CE discipline have identified this area of guidance as useful and helpful.

The third objective, to provide guidance in how to conduct the CE process, has been successfully met. The following are concluded:

- o A system based on the trainee level of competences has enabled to identify the trainee as novice and expert with a 4 level classification: novice 1, novice 2, expert 1 and expert 2.
- o Flexible guidance user interface has been established during the CE process (E-mentor tool) based on the novice/expert recognition. The guidance is in terms of compulsory display of help when required.
- o Both expert and novice cost estimators have validated the approach.

References

AACE International. (2004), *Skills & Knowledge of Cost Engineering* (5th edition), S. Amos Editor.

Abersek, B. and Popov, V. (2004), 'Intelligent Tutoring System for Training in Design and Manufacturing', Advances in Engineering Software, Vol. 35, pp. 461-471.

Asiedu, Y. and Gu, P. (1998), 'Product Life Cost Analysis: State of the Art Review.', Int. J. Produ. Res., Vol. 36, No. 4, pp. 883-908.

Askoxford (2006), Oxford Dictionaries, available at: www.askoxford.com (accessed 15/02/2006).

Attwell, G. (2003), The Challenge of E-Learning in Small Enterprises: Issues for Policy and Practice in Europe, Report from Cedefop Panorama Series, Luxemburg: Office for Official Publication of the European Communities.

Blanchard, P.N. and Tracker, J.W. (2004), *Effective Learning: Systems, Strategies and Practices* (2nd edition), Prentice Hall, New Jersey.

Bloom, B.S., Engelhart, M.D., Furst, E.J., Hill, W.H., and Krathwohl, D.R. (1956), Taxonomy of Educational Objectives: Handbook 1 - The Cognitive Domain, Logman, London.

Boyle, S.P. and Muller, C.B. (1999), 'Electronic Mentoring: Issues to Advance Research and Practice', International Mentoring Association Conference, San Jose State University, Atlanta.

Burns, R. (International Edition) (2000), Introduction to Research Methods, Sage Publications Limited, London.

Coley, F. (2005), Understanding the Cognitive Behaviour of Cost and Design Engineers (MSc thesis), Cranfield University, UK.

Collins Cobuild English Dictionary (1995), Collins Cobuild English Dictionary, Harper Collins, London.

Creese, R.C. and Moore, T. (1990), 'Cost Modeling for Concurrent Engineering', Cost Engineering, Vol. 32, No. 6, pp. 23.

Curran, R., Raghunathan, S. and Price, M. (2004), 'Review of Aerospace Engineering Cost Modelling: The Genetic Causal Approach', Progress in Aerospace Sciences, Vol. 40, pp. 487-534.

DeMarco, A.A. (2005), 'Six Steps to Project Success', Cost Engineering, Vol. 47, No. 9, pp. 12-14.

Dysert, L.R. and Pickett, T.W. (2005), 'So You Think You're an Estimator?', Cost Engineering, Vol. 47, No. 9, pp. 30.

Ensher, E.A., Heun, C. and Blanchard, A. (2003), 'Online Mentoring and Computer-Mediated Communication: New Directions in Research', Journal of Vocational Behavior, Vol. 63, pp. 264-288.

European Schoolnet (2003), Virtual Learning Environment for European Schools: A Survey and Commentary, European Schoolnet, Brussels.

FAA (2002), Life Cycle Cost Estimating Handbook, Federal Aviation Administration, USA.

Flyvbjerg, B. (2001), 'Making Social Science Matter', Cambridge University Press, Cambridge, UK.

Geoffroy, F., Aimeur, E., and Gillet, D. (2002), 'A Virtual Assistant for Web-Based Training In Engineering Education', Intelligent Tutoring Systems. 6th International Conference, ITS 2002, Vol. 2363, Biarritz, Spain, pp. 301-310.

Grant, I.C. (2004), Cost Engineering Training and Development (Msc thesis), Cranfield University, UK.

Gummesson, E. (1991), 'Qualitative Methods in Management Research', Sage publication Ltd, London, UK.

Hamaker, J. (1994), 'But What Will It Cost? The History of NASA Cost Estimating', Readings in Program Control (NASA SP-6103), National Aeronautics and Space Administration, Scientific and Technical Information Office, Washington DC, USA, pp. 25-37.

Hamilton, A.C. and Westney, R.E. (2002), Cost Estimating Best Practices, AACE International Transactions, USA.

Hammaker, J. (2000), SSCAG's 69th Meeting, European Space Agency, Noordwijk, the Netherlands, May 11-12th.

ISPA and SCEA (2003), Parametric Estimating Handbook, available at: www.ispa-cost.org/PEIWeb/Third_edition/newbook.htm (accessed 26/10/2005).

Jayaraman, V. and Srivastava, R. (1996), 'Expert Systems in Production and Operations Management', *International Journal of Operations &* Production Management, Vol. 16, No. 12, pp. 27-44.

JISC The Joint Information Systems Committee (JISC), available at: www.jisc.ac.uk (accessed 05/01/2006).

Jou, M., Zhang, H., and Lin, C. (2005), 'Development of an Interactive E-Learning System to Improve Manufacturing Technology Education', 5th IEEE International Conference on Advanced Learning Technologies (ICALT '05), Min

Jou, Han-Wei Zhang, Chia-Wan Lin, pp. 359-360.

Khan, M.M. (2002), 'Implementing an Intelligent Tutoring System for Adventure Learning', The Electronic Library, Vol. 20, No. 2, pp. 134-142.

Kwak, Y.H. and Watson, R.J. (2005), 'Conceptual Estimating Tool for Technology-Driven Projects: Exploring Parametric Estimate Technique', Technovation, Vol. 25, pp. 1430-1436.

Michau, F., Gentil, S. and Barrault, M. (2001), 'Expected Benefits of Web-Based Learning for Engineering Education: Examples in Control Engineering', European Journal of Engineering Education, Vol. 26, No. 2, pp. 151-168.

Mishra, K., Roy, R., and Souchoroukov, P. (2002), 'Knowledge Reuse: CE2 Focused Training', Practical Aspects of Knowledge Management, 4th International Conference (PAKM 2002), Vienna, Austria, pp. 595-612.

NASA (2002), Cost Estimating Handbook, NASA Independant Program Assessment Office, Hampton, USA.

Moodle (2005), Internet Resource, available at http://www.moodle.org (accessed 11/10/2005)

NASA (2004), Cost Estimating Handbook, available at: ceh.nasa.gov/webhelpfiles/Cost_Estimating_Handbook_NASA_2004.htm (accessed 11/10/2005).

Oberlander, G.D. and Trost, S.M. (2001), 'Predicting Accuracy of Early Cost Estimates Based on Estimate Quality', Journal of Construction Engineering and Management, pp. 173-182.

Office of Government Commerce (2004), Successful Delivery Skills Programme. Skills Framework Assessment Guide, available at: www.ogc.gov.uk/embedded_object.asp?docid=1004953 (accessed 10/11/2005).

Parry, S.B. (1996), 'The Quest for Competences', Training, Vol. 33, No. 7, pp. 48-52.

Pascail, L. (2006), 'The Emergence of the Skills Approach in Industry and Its Consequences for the Training of Engineers', European Journal of Engineering Education, Vol. 31, No. 1, pp. 55-61.

Patel, A., Scott, B. and Kinshuk (2001), ' Intelligent Tutoring: From SAKI to Byzantium', Kybernetes, Vol. 30, No. 5/6, pp. 807-818.

Pricing and Forecasting Group (MoD) (2002), The Acquisition Training and Development Directory [ATDD], available at: www.ams.mod.uk/ams/content/docs/devdir/function.htm (accessed 10/11/2005).

Robson, C. (2002), Real World Research - A Resource for Social and Practitioner-Researchers (2nd edition), Blackwell, Oxford, UK.

Roy, R. (2003), Decision Engineering Report Series, Cranfield University, Cranfield, UK.

Roy, R., Rios, J., Hussla, I., and Hansen, L. (2005a), 'Virtual Cost Engineering Studio (V-CES): the Challenges of a Just-In Time Service for Cost Engineering Professionals', Innovation and the Knowledge Economy: Issues, Applications, Case Studies (Vol. 2, Pp.1477-1485), Intl. Conf. e-Challenges, Ljubljana, Slovenia.

Roy, R., Rios, J., Sagoo, J., Hussla, I., and Hansen, L. (2005b), Virtual Cost Engineering Studio (V-CES): a New Service for Cost Engineering Professionals, European Communities. Strengthening Competitiveness through Production Networks, 6th FP EU, ICT for Enterprise Networking, p.91-101.

Roy, R. and Sackett, P. (2003), Cost Engineering: The Practice and the Future, The Computer and Automated Systems Association of the Society of Manufacturing Engineers, Michigan, United States.

Rush, C. (2002), Formalisation and Reuse of Cost Engineering Knowledge (unpublished PhD thesis), Cranfield University, UK.

Rush, C. and Roy, R. (2000), 'Analysis of Cost Estimating Processes Used Within a Concurrent Engineering Environment Throughout a Product Life Cycle', Proceedings of CE2000 Conference, Lyon, France, pp. 58-67.

Rush, C., Roy, R., and Gorrono, V. (2003), 'Cost Estimating Rationale Capture: Beyond the Aerospace Industry', AACE International Transactions.

Shen, Q., Fong, P. and Deng, M. (2001a), 'Developing and Intelligent System for Teaching Pre-Tender Cost Estimating of Office Building Projects', Inc. Comput Appl Eng Educ, Vol. 9, pp. 26-36.

Shen, Q., Li, H. and Deng, Z. (2001b), 'Intelligent Multimedia for Expertise-Intensive Training in Construction', Logistics Information Management, Vol. 14, No. 5/6, pp. 386-392.

Society of Cost Estimating and Analysis (SCEA). (2006), SCEA (Glossary), available at: www.sceaonline.net (accessed 125/02/2006).

Talbot, C. (2003), 'Studying at a Distance. A Guide for Students', Open University Press Maidenhead, Philadelphia.

U.S. Department of Labor (2006), Occupational Outlook Handbook, Cost Estimators.

V-CES Consortium D1.5 (2005), Report on Functional and Technical Specification of the Virtual Cost Engineering Studio.

V-CES Consortium D2.4 (2005), Report on Prototype Cost Engineering Mentor and V-CES Platform.

V-CES Consortium D6.6 (2006), Business plan.

Woolf, B.P., Eliot, J.B.C. and Stern, M. (2001), 'Growth and Maturity Intelligent Tutoring Systems: a Status Report', K.D.Forbus and P.L. Feltovich Editors, Smart machines in education, AAAI Press & MIT Press.

ANNEX A: PEOPLE PROFILE

Personal background

- What kind of background do you have?

☐ Finance ☐ Manufacturing ☐ Accounting
☐ Design ☐ Management ☐ Other, please specify:______________

- Do you perform any competences as a cost estimator?

☐ Yes ☐ No

If yes:

- How many years of experience do you have related to cost estimating?

☐ Less than 1 year ☐ Between 6 and 10 years
☐ Between 1 and 3 years ☐ More than 10 years
☐ Between 3 and 6 years

- In which industrial sector do you have experience in cost estimating?

☐ Automotive ☐ Plastic components
☐ Semiconductor equipment ☐ Metallic components
☐ Aerospace ☐ Composite components
☐ Defence ☐ Other, please specify: ______________

- Which of the following methodologies have you used?

☐ Detailed or Bottom-up ☐ Analogy ☐ Parametric

- Have you designed a cost model or are you using an existing one from a dedicated software application?

☐ Own designed cost model. Based on:
☐ Detailed (bottom-up) ☐ Analogy ☐ Parametric
☐ Commercial cost estimating software. Please Specify: ______________

- Do you have any type of certification or accreditation as a Cost estimator or Cost Engineer?

☐ No
☐ Yes --------------------- ☐ ACostE
☐ Other, please specify: ______________

- What is your educational background?

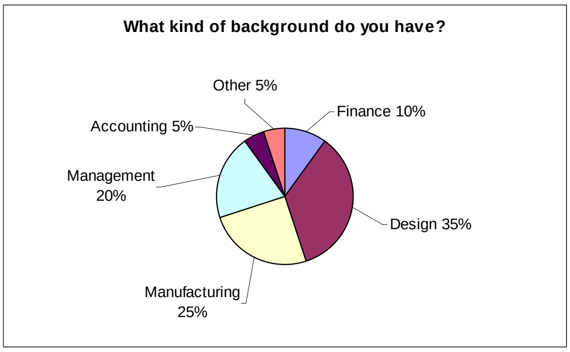
☐ Engineering ☐ Vocational Training
☐ Economics ☐ Other, please specify: ______________

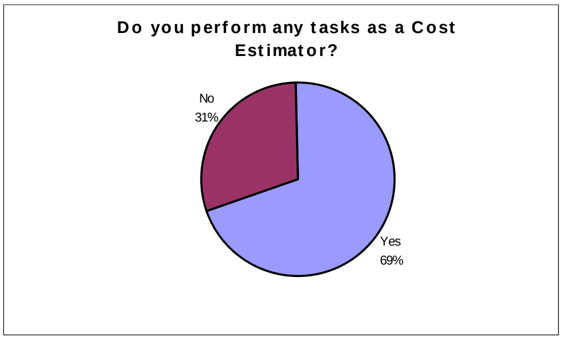
- How many years of experience do you have teaching? ☐

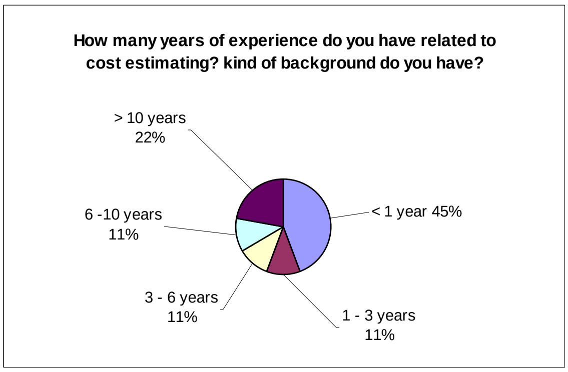
- In which disciplines or subjects?

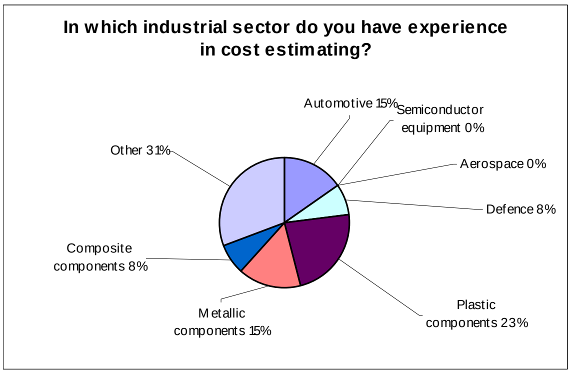
☐

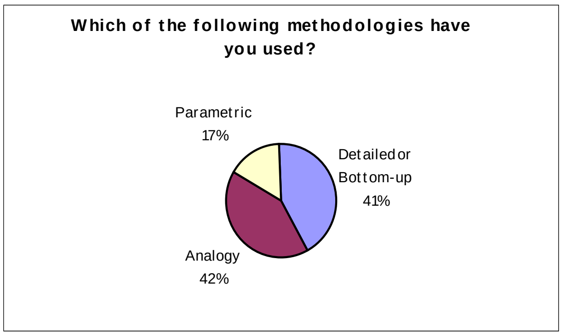
PROFILE FROM TECOS SEMINAR

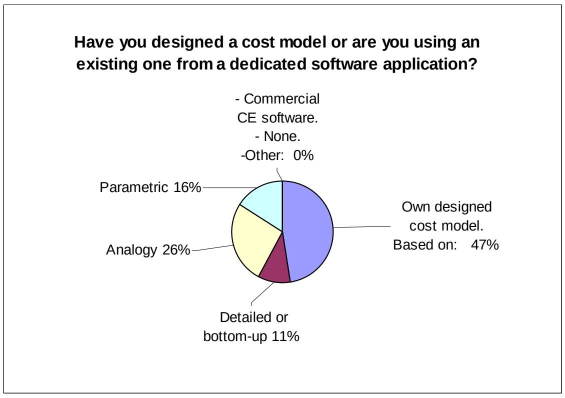


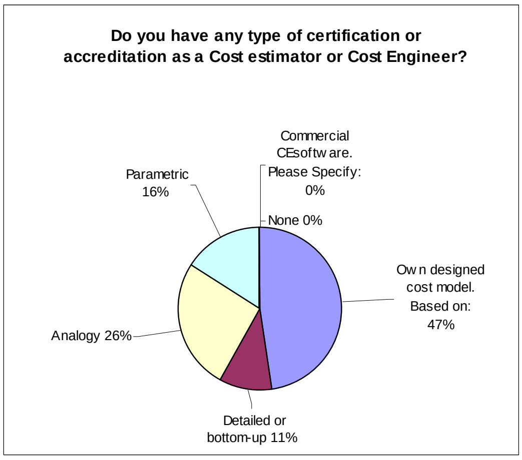


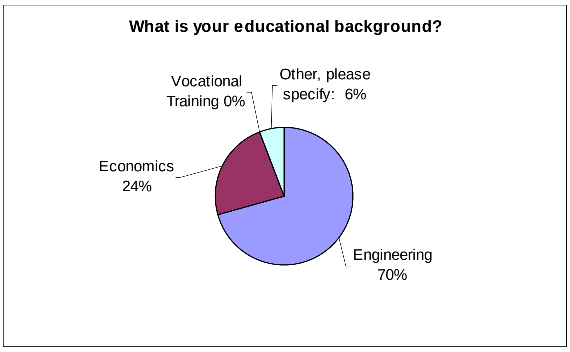












Profile of the participants of the research:

	Job Background	Cost Estimator Experience								Education	Teaching Experience	
		Experience (years)	Sector	Method. Used			Cost Model		Cert. on CE		Years	Subject
				D	A	P	Own design	Com. Sft.				
User 1	Management	> 10	Aerospace.	Yes	Yes	Yes	Yes (D, A and P)	No	No	Eng.	6-7	Aeronautic / Systems Engineering (Quenn's University Belfast)
User 2	Manufacturing	> 10	Aerospace, Defence.	Yes	Yes	Yes	Yes (D and P)	Yes	Yes (ACostE, ISPA Cert.)	Eng.	1	Cost Estimating (in AcostE)
User 3	Cost Management	> 10	Automotive	Yes	Yes	No	Yes (A)	No	Yes (AcostE)	Eng.	0	x
User 4	Manufacturing	3-6	Aerospace, Defence.	Yes	Yes	Yes	Yes (P)	Yes	No	Eng.	0	x
User 5	Manufacturing, Management	> 10	Aerospace	Yes	Yes	Yes	Yes (D and P)	No	Yes (AcostE)	Eng.	0	x
User 6	Management	> 10	Automotive	Yes	Yes	No	Yes (D)	No	No	Econ.	0	x
User 7	Management	> 10	Semicond. Equipment	No	Yes	No	Yes (A)	No	No	Eng.	0	x
User 8	Manufacturing	3-6	(*)	Yes	Yes	Yes	Yes (fuzzy logic, P)	Yes	No (PhD)	Eng.	2	Master Degree by Research in Cost Engineering
User 9	Design, manufacturing	< 1	Metallic components	Yes	No	No	Yes (D)	No	No	Eng.	3	> Mechanical Engineering >Computer Science

	Job Background	Cost Estimator Experience								Education	Teaching Experience	
		Experience (years)	Sector	Method. Used			Cost Model		Cert. on CE		Years	Subject
				D	A	P	Own design	Com. Sft.				
User 10	Manufacturing	1-3	Semicond. Equipment and metallic components	Yes	Yes	No	Yes (D and A)	No	Yes (AcostE)	Eng.	0	x
User 11	Design & manufacturing	1-3	Aerospace	Yes	Yes	Yes	Yes (D, A and P)	SEER-H	No	Eng.	3	Cost Estimating Software
User 12	Manufacturing	> 10	Defence	Yes	Yes	Yes	Yes (D, A)	No	Yes (SCEA Certificate Cost Estimator/Analyst)	Eng.	3	Risk management, Hardware Estimating, Overhead Analysis
User 13	Manufacturing	1-3	Plastic components, other (electronic equipment)	No	Yes	No	Yes (Using Analogy excel spreadsheet)	No	No	Engineering	0	x
User 14	Manufacturing, Design, Management.	No	NA	NA	NA	NA	NA	NA	NA	Engineering	5	Mechanical Engineering (science, design, materials, HNC+degree)

(*) Automotive, Aerospace, Defence, Plastic components, metallic components, composite components

ANNEX B: QUESTIONNAIRES

Questionnaire 1 (form 1) – FRAMEWORK: Suggestion of the CEM

Suggestion of the CEM

Level of project definition

	Level of project/ product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level	CEM
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	1 (low)	Analogy Parametric
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	2 (medium)	Analogy Parametric Detailed
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	3 (high)	Detailed

Table 1
Level project/product definition: expressed as a percent of full completion
Expected accuracy: typical variation in low and high ranges of actual costs from cost estimation after application of contingencies
CEM: Cost estimating methodology

Checking Data and resources available

	YES	NO	CEM
1 - Do you have material cost data? (ex. price material per weight or length, amount of weight or length, rejection rate)			D
2 - Do you have labour cost data? (ex. salaries, fringes, timing component required)			D
3 - Do you have equipment cost data? (ex. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time …)			D
4 - Do you have cost data from a similar previous product/project?			A
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).			A
6 - Do you have statistically significant amount of historical cost data related to previous products/projects?			P
7 - Do you have a way (ex. software tool) to do a statistical analysis of the historical cost data?			P
8 -Do you know the process involved in the life cycle of the product/project you want to estimate?			D

Table 2

Questions in table 2 (figure 7-3) addresses the requirements presented in following table:

Analogy	Detailed	Parametric
- Cost data from a similar project/product - Capability to identify similarities and differences between new and previous project (cost factors).	- Material cost data. - Equipment cost data. - Labour cost data - Knowledge about the manufacturing process.	- Historical data. - Statistical analysis of data

Think of one project/product you had to cost estimate.

Name the type of project/product:

1 - Would you be able to complete the form presented? ☐ Yes ☐ No

2 - Do you think that the questions/answers are relevant to characterise the Cost Estimating Methodology (CEM) to be used (see per each question in form 1 – Tables 1 and 2 – the suitable CEM)? ☐ Yes ☐ No

3 - Would you add any other relevant questions? ☐ Yes ☐ No

-Which and why?

4 - Would you like to have FORM1 starting the e-mentoring process and to suggest to the user, the most suitable CE methodology to be used? ☐ Yes ☐ No

Question	Target
1	Validation of the **approach**: understandable and easy to fill.
2	High level validation of the **content**: requirements.
3	High level validation of the **content**: requirements.
4	Validation of the **approach**: usefulness.

Questionnaire 2 (form 1) – FRAMEWORK: Suggestion of the CEM

Suggestion of the CEM

Level of project definition

	Level of project/product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	1 (low)
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	2 (medium)
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	3 (high)

Table 1
Level project/product definition: expressed as a percent of full completion
Expected accuracy: typical variation in low and high ranges of actual costs from cost estimation after application of contingencies
CEM: Cost estimating methodology

Checking Data and resources available

	YES	NO
1 - Do you have material cost data? (ex. price material per weight or length, amount of weight or length, rejection rate)		
2 - Do you have labour cost data? (ex. salaries, fringes, timing component required)		
3 - Do you have equipment cost data? (ex. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time …)		
4 - Do you have cost data from a similar previous product/project?		
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).		
6 - Do you have statistically significant amount of historical cost data related to previous products/projects?		
7 - Do you have a way (ex. software tool) to do a statistical analysis of the historical cost data?		
8 -Do you know the process involved in the life cycle of the product/project you want to estimate?		

1 - Would you be able to complete the form presented? ☐ Yes ☐ No

2 - Would you like to have FORM1 starting the e-mentoring process and to suggest to the user, the most suitable CE methodology to be used? ☐ Yes ☐ No

Questionnaire 3 (form 1) – FRAMEWORK: Suggestion of the CEM

Suggestion of the CEM

Level of project definition

	Level of project/product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level	CEM
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	1 (low)	Analogy Parametric
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	2 (medium)	Analogy Parametric Detailed
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	3 (high)	Detailed

Table 1
Level project/product definition: expressed as a percent of full completion
Expected accuracy: typical variation in low and high ranges of actual costs from cost estimation after application of contingencies
CEM: Cost estimating methodology

Checking Data available and main resources

	YES	NO	CEM
1 – Do you know which material/s will be used?			D
2 - Do you know which labour will be used?			D
3 - Do you know which equipment (machines) will be used?			D
4 - Do you have cost data from a similar previous product/project?			A
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).			A
6 - Do you have (statistically) significant amount of historical cost data related to previous products/projects?			P
7 - Do you have a way (ex. software tool) to do a statistical analysis of the historical cost data?			P
8 -Do you know the process involved in the life cycle of the product/project you intend to estimate?			D

Table 2, D: Detailed, A: Analogy, P: Parametric

If the detailed CEM was the most suitable methodology according to the previous information provided, the user would then be required to input the information into table 3.

	YES	NO
1 - Do you have or can you get material cost data? (ex. price material per weight or length, amount of weight or length, rejection rate)		
2 - Do you have or can you get labour cost data? (ex. salaries, fringes, timing component required)		
3 - Do you have or can you get equipment cost data? (ex. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time …)		

Table 3

Below table 3 the system will show you a list of the data available in V-CES database of:

- Material (**names**; ex. aluminium).
- Labour (**country and sector**; ex. UK and aero)
- Equipment (**type of machines**; ex. conventional lathe)

"*You have to bear in mind that perhaps you need the material but there is not the exactly grade, or there is not exactly the job position or the exact dimension machine, although is better that not having the information and it can be suitable for the estimating purposes)*".

Think of one project/product you had to cost estimate.

Name the type of project/product:

1 - Would you be able to complete the form presented? ☐ Yes ☐ No

2 - Do you think that the questions/answers are relevant to characterize the Cost Estimating Methodology (CEM) to be used (see per each question in form 1 – Tables 1 and 2 – the suitable CEM)? ☐ Yes ☐ No

3 - Would you add any other relevant questions? ☐ Yes ☐ No

-Which and why?

4 - Would you like to have FORM1 starting the e-mentoring process and to suggest to the user, the most suitable CE methodology to be used? ☐ Yes ☐ No

Question	Target
1	Validation of the **approach**: understandable and easy to fill.
2	High level validation of the **content**: requirements/questions.
3	High level validation of the **content**: requirements/questions.
4	Validation of the **approach**: usefulness.

Questionnaire 4 – IMPLEMENTATION: Suggestion of the CEM

After opening the web page: www.v-ces.com and access the form, user is requested to fill following form.

Suggestion of the methodology

1. Do you feel comfortable with the screen appearance?

2. Think of a real example that you had to estimate.
   a. Name the type of project/product:
   b. Answer to:
      ii. Stage of the project life:
      iii. Q1=
      iv. Q2=
      v. Q3=
      vi. Q4=
      vii. Q5=
      viii. Q6=
      ix. Q7=
      x. Q8=
      xi. QD1=
      xii. QD2=
      xiii. QD3=

   c. Are you satisfied (do you agree) with the answer provided? Why if not?
   [Exercise 2 was done from 3 to 6 times depending on the availability of time]

3. Have you had any doubt when answering the forms? If yes which?

4. Do you find useful the suggestion of the methodology from the e-mentor?

5. General comments:

Question	Target
1	Validation of the **interface**: understandable and easy to fill.
2	Validation of the **questions**: requirements/questions.
3	Validation of the **questions**.
4	Validation of the **feedback**: correctness and usefulness.
5	Validation of the **implementation** in general.

Questionnaire 5 – FRAMEWORK: Suggestion e-training path / Novice & Expert

Suggestion e-training path

<table>
<tr><td colspan="4">Competence example: Data normalisation and calibration</td></tr>
<tr><td colspan="2">Knowledge Test of knowledge</td><td colspan="2">Skills</td></tr>
<tr><td>You know why you have to normalise data (purposes). Problems with raw data.</td><td>☐</td><td>Able to apply inflation rates to the historical data to use (you have done it some time).</td><td>☐</td></tr>
<tr><td>You know in which ways you normalise data.</td><td>☐</td><td>Able to apply currency exchanges to the historical data.</td><td>☐</td></tr>
<tr><td rowspan="2" colspan="2"></td><td>Able to apply production rates to the historical data.</td><td>☐</td></tr>
<tr><td>Model the Theoretical First Piece (T1) to eliminate the quantity affect. This is achieved by eliminating the Cost Improvement Curve effect.</td><td>☐</td></tr>
</table>

1- Is the differentiation between knowledge and skills relevant to you? ☐ Yes ☐ No
2- Would you like to be able to test your knowledge when you are not sure about the knowledge you have in a particular competence? ☐ Yes ☐ No
3- Would you feel comfortable in going through this assessment using a software based environment? ☐ Yes ☐ No

Trainee as Novice or Expert

4- Do you consider reasonable the approach of novice an expert presented (for competence and for methodology)? ☐ Yes ☐ No

Question	Target
1	Validation of the **approach**: knowledge and skills.
2	Validation of the **approach**: having a test to do.
3	Validation of the **approach**: usefulness.
4	Validation of the **approach**: consideration of novice and expert

Questionnaire 5a – FRAMEWORK: Suggestion e-training path

1. Rating of knowledge and skills:

Level	% of knowledge and skills
1	< 50 % of Knowledge
2	>= 50% of Knowledge and < 90% of Knowledge
3	>= 90 % of Knowledge and < 50 % Skills
4	>= 90 % of Knowledge and >= 50 % Skills

Do you think this consideration is acceptable according to the skills and knowledge approach? Why?

2. List the training courses:
   a. The user will be presented with a list of the courses that fit any of his/her interests (where an incremental difference between the current and the target level occurs).
   b. By clicking to each course link you will see the table of content of the course.
   c. Way of listing the courses. The list of courses will be prioritised according how well they fit the interests in terms of:
      i. Number of times (frequency) that course addresses competences which there is a gap between the self-assessment and the target levels (when target> self-assessment).
   d. The list provided is a suggestion. If you want to get enrolled to any course you will have to contact the administrator anyway.

Could you please select the statements you agree or disagree?

	Agree	Disagree
a		
b		
c		
d		

3. Approach: “The person who creates the course (mentor as a teacher) will have to say which competences are addressed and in which level, based on the type of training material you are considering”.

Level	Description	How is it addressed
1	< 50 % of knowledge	Main Purpose: *Declarative Knowledge*. The basic content of the competence is addressed by: - **Lectures** material. - **Discussion** methods.
2	50 < % of K < 90	Main Purpose: *Procedural Knowledge* and *low level skills*. The basic content of the competence is addressed by: - **Low level exercises/assignments** (simulation/games).
3	> 90 % of K And < 50 % S	Main Purpose: High level skills. The basic content of the competence is addressed by: - **High level exercises/assignments** (simulation/games).
4	> 90 % of K And > 50 % S	We won’t provide training for this level.

a. Would you, as a teacher, be able to do it?

Question	Target
1	Validation of the **approach**: % knowledge and skills.
2	Validation of the **approach**: list of courses.
3	Validation of the **approach**: way of matching courses, competences and level of competence.

Questionnaire 6 – FRAMEWORK: Tailor help in the e-mentor process

E-mentor according trainee's expertise

1. Which kind of help would you like to see in the different screens of the e-mentor?

☐ Explanation of the meaning of each field and which type of element is required (number, date…)

☐ An example of the screen filled (in order to see the type of elements required).

☐ Theoretical explanation of what is expected to do in each step.

☐ Example of the steps to carry on for a particular activity and so then be able to fill the screen.

☐ Other, please specify: ____

2. Some of the **tasks** defined to be needed to carry out a cost estimate using the CE process defined by V-CES (as a best practice) are related to one or many **activities** within the CE process.

Assessing the level of these tasks, it would be possible to provide help material to the activities related when using the e-mentor tool. If you have a level on the task equal or inferior to 2 (so you are considered a novice in that task), help material will be displayed compulsory before the activities related to that task.

When carrying on the activity as such you will have a link to that help material anyway either if you are novice or expert. As a novice you may review the content displayed before accessing the activity and as an expert you may feel like refreshing the knowledge related to that activity.

- Do you agree of displaying the help material before the activities if you are considered as a novice (task level =<2)? ☐ Yes ☐ No

Question	Target
1	Validation of the **approach** and the **content**.
2	Validation of the **approach: Compulsories** of the help material

Questionnaire 7 – IMPLEMENTATION: Suggestion of e-training path and Tailor help in the e-mentor process

This implementation is going to be addressed by presenting a case study which comprises and exercise and a questionnaire to be done by the interview.

Name: Date:

PART 1: CASE STUDY – Assessment of competences

I would ask you to do the assessment for a cost estimator based on the CE process using the 3 cost estimating methodologies: analogy, detailed and parametric.

1- The self-assessment can be done manually or using the system evaluation for all the competences, although at the moment the system evaluation has just been implemented for the 3 competences:
- "Cost Estimating Relationships (CER)"
- "Learning Curve (Cost improvement slope)"
- "Data normalisation and calibration"

For the exercise you are just required to use the system assessment for the competence:
"Data normalisation and calibration"

You should assess the rest of the competences manually. It is up to you the use of the system assessment for the competences: "CER" and "Learning curves".

2- The target level per each competence has to be entered manually.

Questionnaire:

1. Did you manage to carry on the assessment? ☐ Yes ☐ No
2. Did you come across to any difficulty during the process? ☐ Yes ☐ No Which?
3. Did you find difficult the knowledge test? ☐ Yes ☐ No

- I did this test extra:

☐ "CER"

☐ "Learning Curve"

4. Do you like to see the courses listed from the most to the less suitable? ☐ Yes ☐ No

Question	Target
1,2,3,4	Validity of the approach

PART 2: CASE STUDY – Data Normalisation to estimate a new Airplane

Airboeing U.S. company is thinking of launching a new airplane for the year 2001. They are in the conceptual stage of the project and they ask you to estimate its cost.

After several meetings between engineers and cost estimators, the following hypotheses have been defined to predict its cost:

1. Possible Weight and T_1 relationship
2. Possible Time (year) related relationship
3. Performance related relationship

After identifying some data sources, the following relationship data presented in the spreadsheet attached (raw_data_airboeing.xls) have been collected. All are airplanes with the same functionality/mission: "bringing passengers from one place to another one".
Before dealing with the information it is necessary to <u>normalise</u> the cost data presented in the spreadsheet. As a cost estimator, you are requested to carry on this step.

- The exercise is prepared with all resources you required. However, you will have internet access in case you want to use any other source.
- You can use the spreadsheet to do the calculations.

Questionnaire:

1- Do you feel comfortable working with Excel? ☐ Yes ☐ No

2- Which normalisation concepts/types are you going to carry on?
 ☐ Anomalies (2.1)
 ☐ Inflation (2.2)
 ☐ Cost Improvement/ Learning Curve (2.3)
 ☐ Different number of engines. (2.4)
 ☐ Technology improvement. (2.5)
 ☐ Different length. (2.6)
 ☐ Consistent scope (2.7)
 ☐ Currency (2.8)
 ☐ Production Rate (2.9)
 ☐ Other. Which (2.10)________________________________

3- Did you get a pop-up help file before the normalisation activity? ☐ Yes ☐ No
 a. If yes. Did you learn?
 ☐ Yes
 ☐ Partially
 ☐ No

4- Have you made use of the help file meanwhile doing the activity (normalisation)?
 ☐ Yes

☐ No

a. If yes. Was it useful?

☐ Yes
☐ Partially
☐ No

5- Could you have done the activity without the help file? ☐ Yes ☐ No

Question	Target
1	Feasible tool to carry on the exercise
2	Understanding the resolution of the exercise
3,4, 5	Feasibility of the implementation

Exercise to Normalise Data: **Data Given**

System Designation	Role	Country Origin	Manufacturer	In Service Date	Fiscal Date	Source UPC in National Currency and Fiscal Date	Currency	Number of units	Length (m)	Dimeter (m)	Wing Area (Sqm)	Mass MTO (Kg)	Max Range (km)	Number of passengers	Number of engines	**Cost data to be used**
A318	Commercial aircraft	France	Airbus	2002	2001	252000000	French Francs	356	31,5	3,96	34,1	38400	6000	107	2	
A319	Commercial aircraft	France	Airbus	1995	1998	274050000	French Francs	294	33,8	3,96	34,1	40100	6800	124	2	
A320	Commercial aircraft	France	Airbus	1987	1998	299250000	French Francs	294	37,6	3,96	34,1	41000	5700	150	2	
A321	Commercial aircraft	France	Airbus	1993	1998	362250000	French Francs	294	44,5	3,96	34,1	47700	5600	185	2	
A330-200	Commercial aircraft	France	Airbus	1997	1998	724500000	French Francs	294	59,0	5,64	60,3	120000	12500	293	2	
A330-300	Commercial aircraft	France	Airbus	1992	1998	806400000	French Francs	294	63,6	5,64	60,3	122200	10500	335	2	
A340-600	Commercial aircraft	France	Airbus	2000	1997	913599999	French Francs	284	75,3	5,64	63,45	177000	13900	380	4	
737-900	Commercial aircraft	USA	Boeing	2000	2000	60000000	US Dollars	233	42,1	3,76	34,3	42900	5084	177	2	
737-700	Commercial aircraft	USA	Boeing	1997	1997	42500000	US Dollars	233	0,3	3,76	34,3	38000	5917	128	2	
767-400ER	Commercial aircraft	USA	Boeing	1999	1999	120000000	US Dollars	232	61,4	5,03	51,9	103000	10500	375	2	
777-300	Commercial aircraft	USA	Boeing	1997	2000	180000000	US Dollars	233	73,9	6,2	60,9	160000	11030	368	2	

Inlfation Rates source:
http://www1.jsc.nasa.gov/bu2/inflateCPI.html

Currency exchange rates

http://www.oanda.com/convert/classic

Slopes of the learning Curve

Criteria 1:	Criteria 2 (Cost Estimator's Reference manual):
75% hand assembly/25% machining = 80%	1. Aerospace 85%
50% hand assembly/50% machining = 85%	2. Shipbuilding 80-85%
25% hand assembly/75% machining = 90%	3. Complex machine tools for new models 75-85%
	4. Repetitive electronics manufacturing 90-95%
	5. Repetitive machining or punch-press operations 90-95%
	6. repetitive electrical operations 75-85%
	7. Repetitive welding operations 90%
	8. Raw materials 93-96%
	9. Purchased Parts 85-88%

Questionnaire 8 – Selection of the list of competences

Here presented is a list of the main competences to be performed in order to undertake a cost estimate using the best practice process for the 3 CEMs: analogy, detailed and parametric.

COMPETENCES (CE process)		
General	Concept of cost estimating	1
	Cost engineering/estimating methodologies	2
	Data normalisation and calibration	3
	Breaking down the project	4
	Drawing and specification reading and analysis	5
	Estimate requirement definition (CARD)	6
	Learning curves (cost improvement slope)	7
	Basic mathematical, statistics & analytical skills	8
	User level in related software applications	9
	Basic Finance and accounting concepts	10
Detailed	Detailed process	11
	Data collection – (Material, Labour, Equipment)	12
	Detailed cost modelling	13
Analogy	Analogy process	14
	Data collection (Design, Manufacturing, Cost, etc.) of strongly similar products.	15
	Development of cost factors	16
Parametric	Parametric process	17
	Definition of hypothesis	18
	Data collection of historical data (manufacturing, design, cost, etc.)	19
	Statistical analysis	20
	Cost Estimating Relationships	21
	Parametric cost modelling	22

Table 1: list of competences to carry on the CE process

1- Thinking of the CE process defined by V-CES as a set of activities to carry on, do you agree with the main competences presented in the list above? [Review before the activities proposed by V-CES project].

☐ Yes ☐ No

2- Would you add/change/remove any competence? ☐ Yes ☐ No

-Which and why?

3- Take a look to the list of skills for a Cost Engineer (and focus on the cluster Cost Estimation) provided by I.C.Grant thesis (see attached). Do you agree with the matching established between list on table 1 and this one? Why?

☐ Yes ☐ No

4- Would you now add/change/remove any competence after having seen this list?

☐ Yes ☐ No

-Which and why?

5- Does it make sense to separate *Data Collection* and *Cost modelling* as different competences per each of the 3 methodologies?

☐ Yes ☐ No

- Why?

Question	Target
1-2	Introduction and first validation of list of competences.
3-4	Validate the list crossing it with a validated list (I.C.Grant). This gives 2 validation purposes: The detailed of competence defined is acceptable, not too much in detailed nor too general. The competences selected in this thesis list (based on the CE process) are contained to some extend to a major list which addresses the skills of a cost engineer and a cost estimator.
5	As the main difference between the 2 list is the separation of *Data Collection* and *Data modelling*, the question particularly addresses if this issue is relevant for the purpose.

	SKILLS	Match with other list
Cost Estimating	Cost control and analysis	
	Cost Estimating	1
	Concept estimating	
	Analysis techniques	
	Detailed “ground up” estimating	11
	Impact on cost of volumes, prototyping, development programmes and learner	
	Establish main ground rules and assumptions	6
	Cost engineering/estimating methodology, practices, tools and techniques	2
	Data collection, assimilation & measurement	12,15,19
	Comparative estimating	14
	Rough order estimating	
	Cost estimating/engineering basics & terminology	
	Estimating allowances	
	Cost modelling	13,16,22
	Cost estimating relationships	21
	Audit	
	Data, information & knowledge management	
	Estimation software tools	
	Cost estimate testing & statistical theory	20
	Life cycle costs	
	Break even analysis	
	Parametric and tools	17
	Time value formulas	
	Risk evaluation and analysis, develop cost range	
	Performance parameters	
	Sensitivity analysis	
	Learning & forecasting techniques	7
	Data mining, normalisation, optimisation and analysis	3
	Estimate requirement definition (CARD)	6
	Cost performance/schedule trade studies	
	Planning and scheduling	
	Cost estimating errors	

	SKILLS	Match with other list
Manufacturing and Engineering	Drawing and specification reading and analysis	5
	Design appreciation	5
	Industry and product specific manufacturing and engineering principles, processes, materials, technology & knowledge.	
	Arithmetical, mathematical skills, statistics, probability, regressions analysis & sampling	8
	System design & integration	
	Computer applications, science, terminology and functions of hardware and software	9
	Quality, inspection, & test techniques	
	Reliability and maintainability	
	Programming skills	
Industrial engineering	Production Process	
	Production Engineering	
	Standard time	
	Work measurement	
	Work Study	
	Industrial engineering	
	Capacity assessment	
Project management	Work & cost breakdown structures and account codes	4
	Documentation skills	
	Project management	
	Standard const control	
	Requirements analysis	
	Earned value management	
	Risk management	
	Integrate disciplines	
	Operations, research, planning, management and control	
	Project definition	
	Configuration management	
	Schedule analysis	

Finance and Accounting	Budgeting and cash flow	
	Capital asset and resource management	
	Charging Rates	
	Cost accounting systems, practices & methods	
	Cost benefit analysis	
	Cost Management	
	Depreciation	10
	Discounting techniques, future value and inflation, present value analysis, rate of return	
	Exchange rates	10
	Financial accounting & analysis	10
	Forecasting	
	Lease/buy analysis, owner's costs	
	Overheads analysis & allocation of Costs	10
	Understanding financial reports	
	Understanding labour and cost rate and their make up	

Initial matching proposed between the list of skills defined by I.C.Grant and the one proposed by the author.

ANNEX C: ANSWERS QUESTIONNAIRES

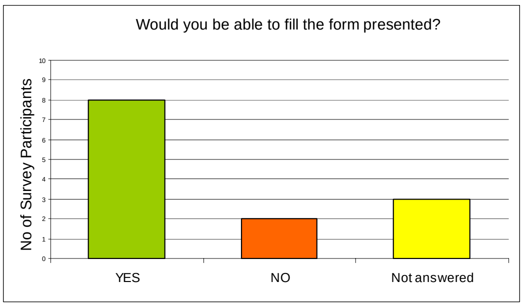
SUMMARISE OF ANSWERS PER EACH ATTENDAND

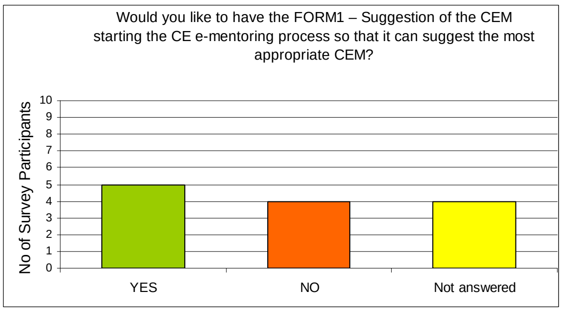
Questionnaire 1 - Framework suggestion CEM

	Type of project/ product	1- Complete form	2- Relevance questions	3- Modify form. Change?	4- Like form
User 1	Composite Fan Cowl Doors	Yes	Yes	**Yes** - For a detailed a structured BOM is required. - Before asking for material, equipment and labour cost data is needed to ask if they know which material, equipment and labour types will be used. In early stages (when you will use analogy or parametric) perhaps you still do not know the exact material. (*)	Yes
User 2	Classified/ Commercial	Yes	Yes	**No** - He thinks this is a good level of detail; more questions are likely to reduce the level of response. - Agreement on (*)	Yes
User 5	Nacelle	No	No (Not particularly)	**Yes** - BOM is required for detailed. - Agreement on (*)	Yes

Experts background and experience details

Questionnaire 2 - Framework suggestion CEM





Questionnaire 3 - Framework suggestion CEM:

	Type of project/ product	1- Complete form	2- Relevance questions	3- Modify form. Change?	4- Like form
User 1	Composite Fan Cowl Doors	Yes	Yes	No	Yes
User 2	Classified/ Commercial	Yes	Yes	No - Think this is a good level of detailed, more questions are likely to reduce the level of response.	Yes
User 3	2 door convertible (Bentley)	Yes	Yes	In real work there would be financial and time constraints.	Yes
User 4	Radomes	Yes	Yes	Yes - Is the cost data reliable?	Yes
User 5	Nacelle	No	No (Not particularly)	No	Yes
User 6	Steering Wheel	Yes	Yes	Yes - Time could be considered according to the complexity of the project/product.	Yes
User 7	Escape Plus (gas treatment machine)	Yes	Yes	No	Yes
User 8	Estimating drilling process (Airbus)	Yes	Yes	No	Yes

Questionnaire 4 – Implementation suggestion CEM (questions):

	Comments to improve
User 1	Screen appearance: 1- Very busy which may be off-putting for some users. But logical and easy to understand. Section 2 Form: 2- Q1: Leave the word materials and get rid off the word BOM. For me, question QD1 is the information contained in a BoM (material, dimensions, price…) 3- Q2 and Q3 are ok: it is incorrect to add number of equipment and labour type as they will be outputs of the cost estimate, never inputs. 4- Add in question Q1, Q2 and Q3 the word all to avoid the user doubting in saying, I would like to answer some instead of yes or no. 5- Q8: Question not clear. Add the work manufacturing and remove project life cycle. 6- Q7: He was first confused about the software meant. He though about Price Systems software such as Price-H. Add in brackets: Excel… 7- QD2: Change “timing component required” by “component runtimes”, as first one is too ambiguous. Project life cycle table: 8- –20% / +30% (add symbol +). 9- Put bid/tender in intermediate stage and not in final. 10- Get rid of the numbers of the preparation effort, they are senseless. Keep just: low, medium and high.
User 2	Screen appearance: 1- Interface less busy, using 2 screens and as focused as possible. Put just the option Preliminary, Intermediate and Final and leave the rest of the information on table 1 (Level of project definition, Expected Accuracy, End usage and Preparation Effort) in a help button, when you press it you see the table in a pop-up screen. Section 2 Form: 2- Q1, Q2, Q3: Why do no you put the option SOME as well? 3- Q5: Do you mean people expertise? 4- Q6: He got confused because he though Parametric model (defining CERs) it was a cost model but not a statistic cost model. 5- Q7: They do not really use any statistics when creating the Parametric model. They apply expert judgement, and the validation process comes from populating the model with real historical data and to see how close is the result with real values. 6- Q8: Say manufacturing process and remove life cycle. Project life cycle table: - ok
User 3	Screen appearance: 1- It is ok. It would be nice to see in a diagram (time in axis, level of project definition) where to apply the methodologies. Section 2 Form: 2- Q5: Do you mean <u>people</u> expertise? 3- Q8: What do you mean by process? Manufacturing process? 4- Customer expectance and time are relevant in real estimates and are not considered as inputs.

	- Why do not you put some in questions from Q1 to Q8? Project life cycle table: - The terminology for the automotive sector is different. Add to intermediate stage, in end usages, Target Cost Setting.
User 4	Screen appearance: 1- Separate the form in two pages. Section 2 Form: 2- Q8: What do you mean by process? Manufacturing process? 3- Customer expectance and time are relevant in real estimates and are not considered as inputs. Project life cycle table: - Get rid of the numbers of the preparation effort, they are senseless. Keep just: low, medium and high. - Change “end usage…” to “Purpose of estimate”.
User 5	Screen appearance: 1- Too crowded, possibly labels could be separated on different screens. Section 2 Form: 2- Q1: BOM is different that material. Remove BOM and keep material Q2: You know the type but not the number. You should ask as well for the number. I may know some 3- Q8: Add manufacturing to process as it is confusing. Life cycle also includes delivering, testing, disposal, etc. are you considering this as well? Project life cycle table: - Budget authorisation should go after bid/tender. –20% / +30% (add symbol +). - He got confused in <10% (he though it meant bigger than 10%)
User 6	Screen appearance: 1- Good. A little crowded. Section 2 Form: 2- Q1: Remove BOM, QD1 has the information contained in the BOM. 3- Q7: Confusing. He didn’t though of Excel (he has never done a parametric). Project life cycle table: 4- Ok
User 7	Screen appearance: - It is ok. Section 2 Form: - Q1: Desire to change components from suppliers instead of materials. This is caused because they assembly, do not manufacture. - In case of leaving materials, remove BOM, as are different things. - Q7: When saying software package, he didn’t though about Excel, for instance. - Q8: It was confusing: what do you mean by process involved during the life cycle? Project life cycle table: - When saying Final stage I would expect to have at least 60-70% of the project level definition and not 40%. This is confusing for me. Founded confusing last stage began with 40% of level of project definition. He was

	expecting 60-70%
User 8	Screen appearance: - Fine. Maybe less information on the screen would be better. He likes having all the information in 1 screen, though 2 screens would be ok as well. In conclusion he would leave it like it is. Section 2 Form: - Q5: He did not understand that it also meant people. Sentence could be simpler. - Q8: It is a bit confusing. Project life cycle table: ok
User 9	Screen appearance: - Good. Because cost estimation is a complex competence, in order to be comprehensive enough the amount of information is required and fine for me. Section 2 Form: Q3: Add tooling a part of machines when considering the equipment. Q7: The question is confusing (he didn't though about Excel, he was thinking of kind of software Price-H). Just answer no because he has never done a statistical analysis of historical data (no parametric used). Q8: The process is really important, bearing in mind that perhaps you will user a new technology or a new manufacturing process. The question is confusing: What do you mean by process involved during life cycle? Q2/QD2 and Q3/QD3: The differentiation is required when outsourcing, for instance. If you want to manufacture in China, as you know the manufacturing process you may be aware of the labour and equipment type (the same as you where using in UK) but you do not know the rates in China.

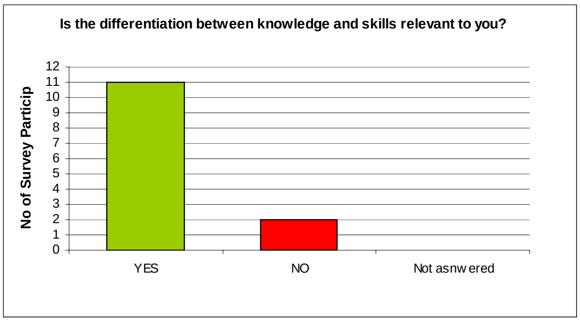
Questionnaire 4 – implementation suggestion CEM (feedback):

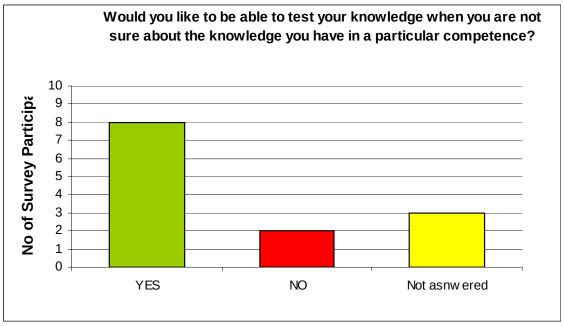
	Comments on feedback	Is the suggestion useful?
User 1	Agreement with the feedback on 5 examples (*). I agree with the feedback and I find it useful. It is a very useful service tool. The suggestion is quite straightforward and clear. The steps are clear. Emphasised comments: - I like to see database data available when user can not provide some.	Yes
User 2	Agreement in all suggestions, except one: you propose me to do detailed but I do not have time to do it (just 2 days!!). Emphasised comments: - "I like the explanation why the methods are not appropriate".	Yes

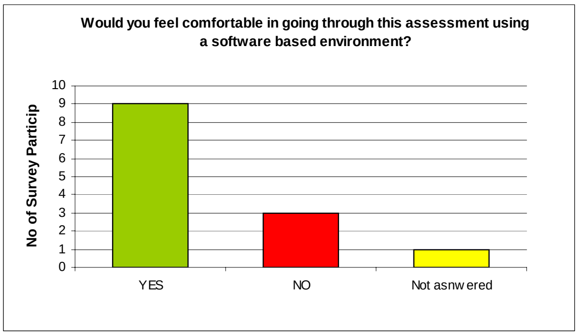
User 3	Agreement with the feedback on 3 examples (*). Emphasised comments: - Structure is ok. - I like explanation about what and why is not suitable. - I like to be suggested as many estimates as suitable cost estimating methodologies, although if the confidence is high, it wouldn't be cost effective to do more than 1 CE, but as a suggestion is ok.	Yes
User 4	Agreement with the feedback on 5 examples (*) (out of 6). In one example, all questions are answered yes but you are in preliminary stage. System tells you that you are probably wrong and you should review the form, but it should give the choice that in preliminary stage, for whatever the reason, you have material, labour and equipment, even if it is strange. It gives the answers expected. Helps and suggestion is something potential customers would look for. Comment could be simpler and clearer in terms of grammar. Emphasised comments: - "I like the idea of presenting the database information".	Yes
User 5	Agreement with the feedback on 6 examples (*). Emphasised comments: - It is useful and the contents are ok, but it needs more clarification in terms of explanation.	Yes
User 6	Agreement with the feedback on 3 examples (*). Emphasised comments: - "I like the explanation about why a methodology is not suitable and the user encouragement to do cost estimates using as many methodologies as possible". - "Very Nice: The suggestions are important to understand how to cover the lacks of information, data or skills".	Yes
User 7	Agreement with feedback on 3 examples (*). Emphasised comments: - After receiving the feedback, when coming back you should be able to see last inputs, as most of times you desire to make some changes from previous version.	Yes
User 8	Agreement with feedback for 4 examples (*) Emphasised comments: - I like to be suggested as many methodologies as suitable. - I like to be presented the data available with material, labour and equipment	Yes
User 9	Agreement with feedback in 4 examples (*). Emphasised comments: - It is really good that what V-CES database can provide is shown, very useful. I also like to see a recommendation to carry on Analogy and Parametric if possible. - The answer is really good. It gives future directions to fulfil competences. It is very straightforward, clear and useful.	Yes

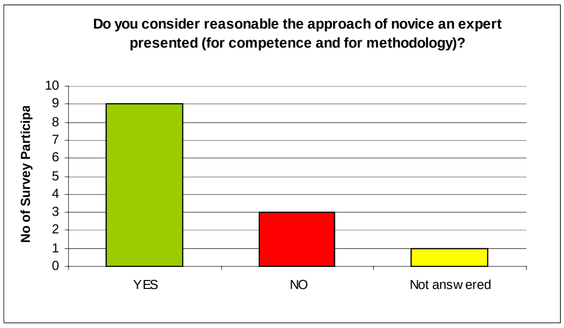
Questionnaire 5 – FRAMEWORK: Suggestion e-training path / Novice & Expert

TECOS:









	1 – Relevance differentiation K&S	2- Test of knowledge	3- Validity/comfort assessment	4-Novice/expert approach
User 1	Yes	Yes	Yes	Yes
User 2	Yes	Yes	Yes	Yes
User 3	Yes	Yes	Yes	Yes
User 4	Yes	Yes	Yes	Yes
User 5	Yes	Yes	Yes	Yes
User 10	Yes	Yes	Yes	Yes
User 12	Yes	Yes	Yes	Yes
User 13	Yes	Yes	Yes	NA (not done limited time)
User 14	Yes	Yes	Yes	NA (not done limited time)

Questionnaire 5a – FRAMEWORK: Suggestion e-training path

	1 – Level of competence based on K&S	2- Listing courses				3- As a teacher be able to grade the course.
		a.	b.	c.	d.	
User 1	Yes	Yes	Yes	Yes	Yes	Yes
User 2	Yes	Yes	Yes	Yes	Yes	Not sure
User 3	Yes	Yes	Yes	Yes	Yes	Yes
User 13	Yes. Somebody may have all the knowledge with no skills	Yes	Yes	Yes. Really liked prioritisation	Yes	Yes
User 14	Yes. Somebody may have all the knowledge with no skills	Yes	Yes	Yes. Really liked prioritisation	Yes	Yes

Questionnaire 6 – FRAMEWORK: Tailor help in the e-mentor process

	1- Type of help					2- Agree with compulsory help for novice?
	Meaning filled	Example filled	Explanation activity	Example carry out activity	Other	
User 1	No	Yes	No	Yes	-	Yes
User 2	Yes	Yes	Yes	Yes	-	Yes
User 3	Yes	Yes	Yes	Yes	-	Yes, but he would like to see a difference in terms of content depending if trainee is novice or expert
User 5	Yes	Yes	Yes	Yes	-	Yes
User 10	No	No	No	Yes	-	Yes
User 12	Yes	Yes	Yes	Yes	-	Yes

Questionnaire 7 – Implementation (feedback):

User	Date execution	Duration (min)	Username	email
9	18/07/2006	90 [Cranfield University]	weidong	w.li@cranfield.ac.uk
11	23/07/2006	120 [Bedford]	oliver	o.houseman@…
12	22/08/2006	105 [Telephone]	clyne	PFGScot2@dpa.mod.uk

CASE STUDY – Assessment of competences

Questionnaire:

1- Did you manage to carry out the assessment? ☐ Yes ☐ No

2- Did you come across to any difficulty during the process? ☐ Yes ☐ No
Which?

3- Did you find the knowledge test difficult? ☐ Yes ☐ No
- I did this extra test:
☐ "CER"
☐ "Learning Curve"

4- Do you like to see the courses listed from the most to the less suitable? ☐ Yes ☐ No

Questionnaire Results				
User	1	2	3	4
9	Yes	"I do not understand the exact meaning of some questions/sentences". Regarding the test (example "Normalisation and Calibration" competence - question 3 of the knowledge test and skills number 11 and 12).	No. (No extra test)	Yes
11	Yes	"I do not understand some of the set of knowledge or questions on the test of knowledge".	No, though the result was not too good. (No extra test)	Yes
12	Yes	- He thought the target level was thinking of his current job and not with his own interests. - De did not understand the meaning of the 4rth set of knowledge: "the achievement of calibration"	No (No extra test)	Yes

Answers of the Assessment (looking at the results in the database):

COMPETENCES (CE process)	User 9		User 11		User 12	
	A	T	A	T	A	T
Concept of cost estimating & terminology	3	4	3	4	3	3
Cost engineering/estimating methodologies	3	4	3	4	3	3
Data normalisation and calibration	**1**	**4**	**1**	**2**	**2**	**3**
Breaking down the project	2	4	2	4	4	4
Documentation and data management	3	4	3	3	3	4
Drawing and specification reading and analysis	2	4	3	4	3	3
Industry and general manufacturing knowledge	3	4	4	4	3	3
Estimate requirement definition (CARD)	2	4	2	2	2	3
Learning curves (cost improvement slope)	2	4	3	4	3	3
Basic mathematical, statistics & analytical skills	2	4	4	4	2	2
User level in related software applications	2	4	4	4	3	3
Basic Finance and accounting concepts	1	3	3	4	3	3
Risk evaluation and analysis	1	3	3	4	3	3
Audit	1	3	1	2	3	3
Detailed process	3	4	3	4	3	3
Data collection – (Material, Labour, Equipment)	2	3	4	4	3	3
Product specific manufacturing process	3	4	3	4	2	3
Detailed cost modelling	2	3	3	3	3	3
Estimating allowances	1	3	2	3	3	3
Analogy process	2	4	2	3	2	3
Data collection (Design, Manufacturing, Cost, etc.) of strongly similar products.	2	3	4	4	2	3
Development of cost factors	2	4	3	3	3	3
Parametric process	3	4	2	3	2	3
Definition of hypothesis	2	3	3	3	2	3
Data collection of historical data (manufacturing, design, cost, etc.)	2	3	4	4	2	3
Statistical analysis	2	3	3	4	2	3
Cost Estimating Relationships	2	3	3	4	3	3
Parametric cost modelling	3	4	2	3	1	2

Test Answers

USER 9

- **Knowledge** set not answered as there was already the test result.

Skills (You are able to…)	**Yes/No**
1- Apply inflation rates to the historical data to use.	Yes
2- Apply currency exchanges to the historical data.	Yes
3- Apply production rates to the historical data.	Yes
4- Model the Theoretical First Piece (T1) to eliminate the quantity affect. This is achieved by eliminating the Cost Improvement Curve effect.	No
5- Separate non-recurring and recurring costs to the historical data.	Yes
6- Adjust for consistent scope.	No
7- Adjust for anomalies.	Yes
8- Able to identify the companies technologies were a productivity advantage is evident.	Yes (doubt on question)
9- Able to identify third party productivity through supplier assessments.	No
10- Able to manipulate the commercial model to reflect historical experience of the organisation regarding Products.	Yes
11- Able to manipulate the commercial model to reflect accounting practices and organisational structure of the company.	No
12- Use a calibrating tool.	No

Test of knowledge mark= +4.33/10

Question	1	2	3	4	5	6	7	8	9	10
Correct	Yes	Yes	Not An	Yes	Yes	Yes	No	No	No	Yes
Value	+1	+1	0	+1	+1	+1	-1	-1/3	-1/3	+1

Level on competence: Data Normalisationa and calibration”	1

List of courses suggested:

1- Parametric (course_id=25) -- 6 times matched

2- Fundamental Skills and Knowledge of Cost Engineering (course_id=22) -- 4 times matched

3- Quantitative Analysis Techniques (course_id=23) -- 3 times matched

4- The estimating process (course_id=24) -- 3 times matched

USER 11

Knowledge (You know…)	Yes/No
1- (the) Purpose to normalise data. Problems with raw data.	Yes
2- (the) Ways you normalise data.	No
3- (the) Purpose and steps of the calibration process	Yes
4- (the) Achievements with calibration.	Yes

Skills (You are able to…)	Yes/No
1- Apply **inflation rates** to the historical data to use.	No
2- Apply **currency exchanges** to the historical data.	No
3- Apply **production rates** to the historical data.	Yes
4- Model the Theoretical First Piece (T1) to eliminate the **quantity affect**. This is achieved by eliminating the Cost Improvement Curve effect.	No
5- Separate **non-recurring** and **recurring costs** to the historical data.	Yes
6- Adjust for **consistent scope.**	No
7- Adjust for **anomalies**.	No
8- Able to identify the companies technologies were a productivity advantage is evident.	Yes
9- Able to identify third party productivity through supplier assessments.	No
10- Able to manipulate the commercial model to reflect historical experience of the organisation regarding **Products.**	No
11- Able to manipulate the commercial model to reflect accounting practices and **organisational** structure of the company.	No
12- Use a calibrating tool.	No

Test of knowledge mark = +3/10

Question	1	2	3	4	5	6	7	8	9	10
Correct	Yes	Not An	Yes	No	Yes	No	Yes	No	Yes	No
Value	+1	0	+1	-1/3	+1	-1	+1	-1/3	+1	-1/3

Level on competence: Data Normalisationa and calibration”	1

List of courses suggested:

1- Parametric (course_id=25) – 3 times matched

2- The estimating process (course_id=24) – 1 matched

USER 12

Knowledge (You know…)	Yes/No
1- (the) Purpose to normalise data. Problems with raw data.	Yes
2- (the) Ways you normalise data.	Yes
3- (the) Purpose and steps of the calibration process	Yes
4- (the) Achievements with calibration.	No

Skills (You are able to…)	Yes/No
1- Apply inflation rates to the historical data to use.	Yes
2- Apply currency exchanges to the historical data.	Yes
3- Apply production rates to the historical data.	No
4- Model the Theoretical First Piece (T1) to eliminate the quantity affect. This is achieved by eliminating the Cost Improvement Curve effect.	Yes
5- Separate non-recurring and recurring costs to the historical data.	Yes
6- Adjust for consistent scope.	Yes
7- Adjust for anomalies.	Yes
8- Able to identify the companies technologies were a productivity advantage is evident.	No
9- Able to identify third party productivity through supplier assessments.	No
10- Able to manipulate the commercial model to reflect historical experience of the organisation regarding Products.	Yes
11- Able to manipulate the commercial model to reflect accounting practices and org anisational structure of the company.	No
12- Use a calibrating tool.	No

Test of knowledge mark = +10/10

Question	1	2	3	4	5	6	7	8	9	10
Correct	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Value	+1	+1	+1	+1	+1	+1	+1	+1	+1	+1

Level on competence: Data Normalisationa and calibration”	2

List of courses suggested:

1- Parametric (course_id=25) -- 6 times matched

2- Fundamental Skills and Knowledge of Cost Engineering (course_id=22) -- 1 times matched

3- Quantitative Analysis Techniques (course_id=23) -- 1 times matched

4- The estimating process (course_id=24) -- 1 times matched

CASE STUDY – Normalisation of data. Estimate a new Airplane *Airboeing*

Questionnaire:

1- Do you feel comfortable working with Excel? ☐ Yes ☐ No

2- Which normalisation concepts/types are you going to carry on?
- ☐ Anomalies (2.1)
- ☐ Inflation (2.2)
- ☐ Cost Improvement/ Learning Curve (2.3)
- ☐ Different number of engines (2.4)
- ☐ Technology improvement (2.5)
- ☐ Different length (2.6)
- ☐ Consistent scope (2.7)
- ☐ Currency (2.8)
- ☐ Production Rate (2.9)
- ☐ Other. Which (2.10)_____________________________

3- Did you get a pop-up help file before the normalisation activity? ☐ Yes ☐ No

a. If yes. Did you appreciate to receive it before the start of the activity?
- ☐ Yes
- ☐ Partially
- ☐ No

4- Have you made use of the help file meanwhile doing the activity (normalisation)?
- ☐ Yes
- ☐ No

b. If yes. Was it useful?
- ☐ Yes
- ☐ Partially
- ☐ No

5- Could you have done the activity without the help file? ☐ Yes ☐ No

Questionnaire results														
User	1	2										3	4	5
		2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	2.10			
1	Yes	No	Yes	No	Yes	Yes	Yes	No	Yes	No	Mass and max range	Yes a. yes	Yes. a. Partially (LC and consistent Scope)	No
2	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	No	Yes a. yes	Yes. a. Yes (LC)	No
3	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	No	Yes a. yes, no need	Yes. a. Yes (Production rate and LC)	No

Questionnaire 8 – Validation of the list of competences (feedback):

	1.- Agreement with competences list 1	2- Competences added, changed or removed.
I.C.Grant	Yes	Add: - Knowledge on the process involved. - Data management/documentation during the CE process.
Paul Shields	Yes	Add: - Knowledge of manufacturing process. - Knowledge of BOM structure.
Alan Lea	Yes	Add: - Knowledge and understanding of Manufacturing processes.
Dale Shermon	Yes	Add: - Risk.

3- Take a look to the list of skills for a Cost Engineer (and focus on the cluster Cost Estimation) provided by I.C.Grant thesis. Do you agree with the matching established between list on table 1 and this one?

	SKILLS	Match with other list	I.C.Grant	Paul Shields	Alan Lea	Dale Shermon
Cost Estimating	Cost control and analysis		No	No	No	
	Cost Estimating	1	1	1	1	1
	Concept estimating		No	No	No	14,17
	Analysis techniques		8 (partial)	No	No	No
	Detailed "ground up" estimating	11	11	11	11	11
	Impact on cost of volumes, prototyping, development programmes and learner		4 (partial)	No (partial with LC)	No (partial with LC)	No
	Establish main ground rules and assumptions	6	6	6	6	6
	Cost engineering/estimating methodology, practices, tools and techniques	2	2	2	2	2
	Data collection, assimilation & measurement	12,15,19	12,15,19	12,15,19	12,15,19	12,15,19
	Comparative estimating	14	14	14	14	14
	Rough order estimating		No	No	No	14,17
	Cost estimating/engineering basics & terminology		1	1	1	1
	Estimating allowances		No (*)	No (*)	No (*)	No
	Cost modelling	13,16,22	13,16,22	13,16,22	13,16,22	13,16,22
	Cost estimating relationships	21	21	21	21	21
	Audit		No (*)	No (*)	No (*)	No
	Data, information & knowledge management		No (*)	No (*)	No (*)	No (*)
	Estimation software tools		No	No	No	No
	Cost estimate testing & statistical theory	20	20	20	20	20
	Life cycle costs		No	No	No	No
	Break even analysis		No	No	No	No
	Parametric and tools	17	17	17	17	17
	Time value formulas		No	No	No	No
	Risk evaluation and analysis, develop cost range		No	No	No	No (*)

	Performance parameters		No	No	No	No
	Sensitivity analysis		No	No	No	No
	Learning & forecasting techniques	7	7	7	7	7
	Data mining, normalisation, optimisation and analysis	3	3	3	3	3
	Estimate requirement definition (CARD)	6	6	6	6	6
	Cost performance/schedule trade studies		No	No	No	No
	Planning and scheduling		No	No	No	No
	Cost estimating errors		No	No	No	No

	SKILLS	Match with other list	I.C.Grant	Paul Shields	Alan Lea	Dale Shermon
Manufacturing and Engineering	Drawing and specification reading and analysis	5	5	5	5	5
	Design appreciation	5	5	5	5	5
	Industry and product specific manufacturing and engineering principles, processes, materials, technology & knowledge.		No (*)	No (*)	No (*)	No (*)
	Arithmetical, mathematical skills, statistics, probability, regressions analysis & sampling	8	8	8	8	8
	System design & integration		No	No	No	No
	Computer applications, science, terminology and functions of hardware and software	9	9	9	9	9
	Quality, inspection, & test techniques		NO	NO	NO	NO
	Reliability and maintainability		NO	NO	NO	NO
	Programming skills		NO	NO	NO	NO
Industrial engineering	Production Process		No (*)	No (*)	No (*)	No (*)
	Production Engineering		No (*)	No (*)	No (*)	No (*)
	Standard time		No (*)	No (*)	No (*)	No (*)
	Work measurement		NO	NO	NO	NO
	Work Study		NO	NO	NO	NO
	Industrial engineering		NO	NO	NO	NO
	Capacity assessment		NO	NO	NO	NO
Project management	Work & cost breakdown structures and account codes	4	4	4	4	4
	Documentation skills		No (*)	No (*)	No (*)	No (*)
	Project management		NO	NO	NO	NO
	Standard const control		NO	NO	NO	NO
	Requirements analysis		NO	NO	NO	NO
	Earned value management		NO	NO	NO	NO
	Risk management		NO	NO	NO	NO
	Integrate disciplines		NO	NO	NO	NO
	Operations, research, planning, management and control		NO	NO	NO	NO
	Project definition		NO	NO	NO	NO
	Configuration management		NO	NO	NO	NO
	Schedule analysis		NO	NO	NO	NO
Finance	Budgeting and cash flow		NO	NO	NO	NO
	Capital asset and resource management		NO	NO	NO	NO
	Charging Rates		NO	NO	NO	NO

	Cost accounting systems, practices & methods		NO	NO	NO	NO
	Cost benefit analysis		NO	NO	NO	NO
	Cost Management		NO	NO	NO	NO
	Depreciation	10	10	10	10	10
	Discounting techniques, future value and inflation, present value analysis, rate of return		No	No	No	10
	Exchange rates	10	10	10	10	10
	Financial accounting & analysis	10	10	10	10	10
	Forecasting		No	No	No	10
	Lease/buy analysis, owner's costs		NO	NO	NO	NO
	Overheads analysis & allocation of Costs	10	10	10	10	10
	Understanding financial reports		NO	NO	NO	NO
	Understanding labour and cost rate and their make up		NO	NO	NO	NO

No → Skill that after agreeing that there is no directly relation with any of the competence presented on the thesis list, it is **no** considered to be included in the list. Reason: it is not a main competence (which required a set of knowledge and skills) to carry on during the CE process based on the 3 methodologies: analogy, parametric and detailed.

No (*) → Skill that after agreeing that there is no directly relation with any of the competence presented on the thesis list, it is considered to be included in the list (it does not mean exactly with the same name, but the concept has to be included in some way). Reason: it is a main competence (which required a set of knowledge and skills) to carry on during the CE process based on the 3 methodologies: analogy, parametric and detailed.

	4- Would you now add/change/remove any competence after having seen this list? Which?
I.C.Grant	Yes. Competences that should be added: - Audit (general). - Estimating allowances (in the detailed cluster), they have to be justified trough the data collection as well. - Process involved. (for the detailed you have to know deeply the manufacturing process, for the other 2 methodologies there is no need). For the 3 methodologies there is a need to understand the way the company works anyway. - Documentation and data management (general). Competences that should be changed: - Add the word "terminology" to the competence "Concept of Cost Estimating".
Paul Shields	Yes. Competences that should be added: - Audit (general). - Estimating Allowances/Contingencies (in the detailed cluster). - Process involved. (for the detailed you have to know deeply the manufacturing process, for the other 2 methodologies there is no need). For the 3 methodologies there is a need to understand the way the company works anyway. - Documentation and data management (general). Competences that should be changed: - Add the word "terminology" to the competence "Concept of Cost Estimating".

Alan Lea	Yes. Competences that should be added: - Audit (general). - Estimating Allowances (in the detailed cluster), they have to be justified trough the data collection as well. - Manufacturing process involved. (for the detailed you have to know deeply the manufacturing process, for the other 2 methodologies there is no need). For the 3 methodologies there is a need to understand the way the company works anyway. - Documentation and data management (general). Competences that should be changed: - Add the word “terminology” to the competence “Concept of Cost Estimating”.
Dale Shermon	Yes. Competences that should be added: - Risk evaluation and analysis, develop cost range. - Manufacturing process. (for the detailed you have to know deeply the manufacturing process, for the other 2 methodologies there is no need). For the 3 methodologies there is a need to understand the way the company works anyway. - Documentation and data management (general). Competences that should be changed: - Add the word “terminology” to the competence “Concept of Cost Estimating”.

ANNEX D: VERSIONS OF THE FORM

VERSION 1:

Level of project definition

	Level of project/ product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	1 (low)
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	2 (medium)
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	3 (high)

Table 1
Level project/product definition: expressed as a percent of full completion.
Expected accuracy: typical variation in low and high ranges of actual costs from cost estimation after application of contingencies
CEM: Cost estimating methodology.

Checking Data and resources available

	YES	NO
1 - Do you have material cost data? (ex. price material per weight or length, amount of weight or length, rejection rate)		
2 - Do you have labour cost data? (ex. salaries, fringes, timing component required)		
3 - Do you have equipment cost data? (ex. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time …)		
4 - Do you have cost data from a similar previous product/project?		
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology)		
6 - Do you have statistically significant amount of historical cost data related to previous products/projects?		
7 - Do you have a way (ex. software tool) to do a statistical analysis of the historical cost data?		
8 -Do you know the process involved in the life cycle of the product/project you want to estimate?		

VERSION 2:

Level of project definition

	Level of project/product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	1 (low)
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	2 (medium)
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	3 (high)

Table 1
Level project/product definition: expressed as a percent of full completion.
Expected accuracy: typical variation in low and high ranges of actual costs from cost estimation after application of contingencies
CEM: Cost estimating methodology

Checking Data available and main resources

	YES	NO
1 – Do you know which material/s will be used, Bill of Materials?		
2 - Do you know which labour types will be required?		
3 - Do you know which equipment type (machines) will be used?		
4 - Do you have cost data from a similar previous product/project?		
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).		
6 - Do you have (statistically) a significant amount of historical cost data related to the previous products/projects?		
7 - Do you possess software tools or other bespoke packages to perform statistical analysis of the historical cost data?		
8 -Do you know the process involved in the life cycle of the product/project you intend to estimate?		

Then if Detailed Cost Estimating is a suitable methodology a second asking for the material, labour and equipment cost data is shown.

	YES	NO
1 – Are you able to obtain material cost data? (e.g. price of the material per weight or length, amount of weight or length, rejection rate)		
2 - Are you able to obtain labour cost data? (e.g. salaries, fringes, timing component required)		
3 - Are you able to obtain equipment cost data? (e.g. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time)		

VERSION 3:

Level of project definition

	Level of project/product definition (%)	Expected accuracy	End usage (typical purpose of estimate)	Preparation effort level
☐ Preliminary	<10 %	-30% / +50%	Screening, Conceptual study or Feasibility	1 (low)
☐ Intermediate	10% – 40%	-15% / +30%	Budget, Authorization, or Control	2 (medium)
☐ Final	>40%	-5% / +15%	Control, Bid/Tender or Check estimate	3 (high)

Table 1
Level project/product definition: expressed as a percent of full completion.
Expected accuracy: typical variation in low and high ranges of actual costs from cost estimation after application of contingencies
CEM: Cost estimating methodology.

Checking Data available and main resources

	YES	NO
1 – Do you know which material/s will be used, Bill of Materials?		
2 - Do you know which labour types will be required?		
3 - Do you know which equipment type (machines) will be used?		
4 - Do you have cost data from a similar previous product/project?		
5 - Do you have any data or internal expertise to support the rational of similarities and differences between projects/products (in terms of requirements, design, manufacturing and/or technology).		
6 - Do you have (statistically) a significant amount of historical cost data related to the previous products/projects?		
7 - Do you possess software tools or other bespoke packages to perform statistical analysis of the historical cost data?		
8 -Do you know the process involved in the life cycle of the product/project you intend to estimate?		

Then if Detailed Cost Estimating is a suitable methodology a second asking for the material, labour and equipment cost data is shown.

	YES	SOME	NO
1 – Are you able to obtain material cost data? (e.g. price of the material per weight or length, amount of weight or length, rejection rate)			
2 - Are you able to obtain labour cost data? (e.g. salaries, fringes, timing component required)			
3 - Are you able to obtain equipment cost data? (e.g. capital cost, installation cost, maintenance cost, machine dimensions, maintenance cost, floor space price, machine lifetime, machines power value, cycle time)			

ANNEX E: DEFINITION OF INITIAL TABLE PROJECT DEFITION

This annex details the process to define the initial table to describe the project definition in the form to suggest the suitable CEM.

Generic Estimate Classification Matrix (AACE, 2004)

	Primary Characteristic	Secondary Characteristic			
ESTIMATE CLASS	LEVEL PROJECT DEFINITION (% of complete definition)	END USAGE Typical purpose of estimate	METHODOLOGY Typical estimating method	EXPECTED ACCURACY RANGE [a]	PREPARATION EFFORT [b]
Class 5	0% to 2%	Screening or feasibility	Stochastic or Judgement	4 to 20	1
Class 4	1% to 15%	Concept Study or Feasibility	Primarily Stochastic	3 to 20	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	Mixed, but Primarily Stochastic	2 to 6	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	Primarily Deterministic	1 to 3	5 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	1	10 to100

Notes:
[a] Typical variation in low and high ranges. If the range index value of “1” represents +10/-5%, then an index value of 10 represents +100%/-50%.
[b] Typical degree of effort relative to least cost index of 1. If the cost index value of “1” represents 0.005% of project costs, then an index value of 100 represents 0.5%.

Estimate Classification Matrix for “Process Industries” (AACE, 2004)

	Primary Characteristic	Secondary Characteristic			
ESTIMATE CLASS	LEVEL PROJECT DEFINITION (% of complete definition)	END USAGE Typical purpose of estimate	**METHODOLOGY** Typical estimating method	EXPECTED ACCURACY RANGE [a]	PREPARATION EFFORT [b]
Class 5	0% to 2%	Concept Screening	Capacity Factored, **Parametric Models**, Judgement, or **Analogy**	L= -20% to –50% H= +30% to +100%	1
Class 4	1% to 15%	Study or Feasibility	Equipment Factored or **Parametric Models**	L= -15% to –30% H= +20% to +50%	2 to 4
Class 3	10% to 40%	Budget, Authorization, or Control	**Semi-Detailed** Unit Costs with Assembly Level Line Items	L= -10% to –20% H= +10% to +30%	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	**Detailed** Unit Cost with Forced Detailed Take-Off	L= -5% to –15% H= +5% to +20%	4 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	**Detailed** Unit Cost with Detailed Take-Off	L= -3% to –10% H= +3% to +15%	5 to100

Notes:
[a] Typical variation in low and high ranges. If the range index value of “1” represents +10/-5%, then an index value of 10 represents +100%/-50%.
[b] Typical degree of effort relative to least cost index of 1. If the cost index value of “1” represents 0.005% of project costs, then an index value of 100 represents 0.5%.

Adaptations of previous tables are listed below:

- From 5 to 3 classes. The main driver when grouping the classes has been the CE Methodologies achieved by new classes in terms of Analogy, Detailed and Parametric and the logical adaptation of the range percentages of level of product/project definition (as it is the main characteristic).
- Product/project development stage names change to make them meaningful.
    - Class (1+2) →Final
    - Class 3 → Intermediate
    - Class (4+5) → Preliminary
- Adjust the suitable cost estimating methodologies to the 3 targeted by the study: Analogy, Parametric and Detailed.
- End usages by adding the end usages from previous 5 classes, proposed by generic matrix proposed by AACE.
- Preparation effort is represented in a more qualitative way with the purpose to show the trend of increasing the effort required according the level of project definition increases.
- Accuracy. The desired to have it in % (but just done for the Process Industries) and in simple format (not in Low and High Level as done for Process Industries) → Start point use the 3 class proposed by ANSI Z94.0.

  Then get new values from interviews in order to:
    - Achieve the sectors: aerospace, automotive and semiconductor-equipment.

Be aware that ANSI Z94.0 classification does not exactly match with the grouping classes done by this study.

ANNEX F: CODING SUGGESTION CEM

Variable	Comment
Comment_A1	"You should look for the data or identify someone to support the rational similarities and differences between projects/products before starting an Analogy Cost Estimate".
Comment_A	"You should first identify a similar previous product/project and then look for its cost data. If you can not do this, then the Analogy Methodology is not suitable".
Comment_P1	"You need a tool to develop a statistical analysis; if you do not have this you should not start the Parametric Methodology".
Comment_P	"You should first identify a significant amount of historical data related to previous products/projects. If you can not do this, Parametric Methodology is not suitable".
Comment_D	"If you do not know the materials, labour and equipment involved, or the process involved in the life cycle of the product/project, you can not go for the Detailed Methodology".

___Suitability CEM according to questions (part 2 of the form)___________________________

```
If (Q4=yes) then
        If (Q5=yes) then
        A=yes
        Else If (Q5=no) then
        Print Comment_A1
        End if
Else If (Q4=no) then
Print Comment_A
End if

If (Q6=yes) then
        If (7=yes) then
        P=yes
        Else If (Q7=no) then
        Print Comment_P1
        End if
Else If (Q6=no) then
Print Comment_P
End if

If (Q1=Q2=Q3=Q8=yes) then
        D1=yes
        else
        D1=no
        Print Comment_D
End if
```

If (preliminary=yes) then

If (D1=yes) then
Print "You are probably **not** on the ***Preliminary Stage*** as you should not have a clear picture about materials, labour, equipment and the manufacturing project life cycle. Could you please reconsider the project level definition or redefine questions 1, 2, 3 and 8?"

Else If (A=yes and P=yes) then
Print "You can use **both Analogy and Parametric Methodologies**. E-mentor suggests you create two cost estimates using both methodologies. This will allow you to <u>check</u> the results and be <u>more confident</u> about the outcome.

If time is a constraint and you have to select just <u>one</u> methodology your decision should bear in mind:

- Targeting the <u>accuracy</u> to achieve (quality of data and resources):
  - The **similarity** with the **previous project/product** is really strong, better than the relevance with the historical data available, then **Analogy** Methodology.
  - The relevance of the **historical data** available is better than the similarity with the previous project/product, then **Parametric** Methodology.

- If you have the required data/resources the Analogy Methodology will probably take less time than the Parametric Methodology".

Else If (A=no and P=yes) then
According to your current availability of data, resources and project phase you should carry on the **Parametric Methodology**.

The Analogy Methodology is not suitable for the reason: *Comment_A*
If you have the time and you can achieve the requirements missing for the Analogy Methodology, E-mentor suggests you to do the estimate using both methodologies to verify and be <u>more confident</u> of the result.

Else If (A=yes and P=no) then
According to your current availability of data, resources and project phase you should carry out the **Analogy Methodology**.

The parametric is not suitable for the reason: *Comment_P*
If you have the time and you can achieve the requirements missing for the Parametric Methodology, E-mentor suggests you to do the estimate using both methodologies to verify and be <u>more confident</u> of the result.

Else If (A=no and P=no) then
You do **not** fulfil any of the **minimum requirements** needed to start the CE process using either the Analogy or Parametric Methodologies.
The requirement to start the Analogy is:
- *Comment_A*
The requirement to start the Parametric is:
- *Comment_P*

End if
End if

ElseIf (intermediate=yes) then

If (D1=yes) then

Go to do the second form.

If [(QD1=yes) and (QD2=yes) and (QD3=yes)] then
D=yes
Else
D= no
End if

End if

If (D=yes) then

If (A=no and P=yes) Then
According to your current availability of data, resources and project phase you should carry on the **Detailed and/or the Parametric Methodologies**. E-mentor suggests you do both.
If time is a constraint, and you have to select just <u>one</u> methodology your decision should bear in mind:

- Try to do the **Detailed first**, as you will probably have to use this methodology for future estimates when the project is the final stage.

- If the relevance of historical data available is really good and you have already done data collection, the creation of a **Parametric** cost model may reach similar accuracy as the Detailed Methodology and it will take less <u>time</u>.

Analogy Methodology is not suitable for the reason: *Comment_A*

If you have the time and you can achieve the requirements missing for the Analogy, E-mentor suggests you do the estimate using both methodologies to verify and be <u>more confident</u> of the result.

Else If (A=yes and P=no) then
According to your current availability of data, resources and project phase you should carry on the **Detailed and/or the Analogy Methodology**. E-mentor suggests you to do both.
If time is a constraint, and you have to select just <u>one</u> methodology your decision should bear in mind:

- Try to do the **Detailed first**, as anyway you will probably have to use this methodology for future estimates when the final stage of the project.

- **Analogy** will probably be **less time** consuming, but unless the similarity is really strong you will get less accuracy.

Parametric Methodology is not suitable for the reason: *Comment_P*

If you have the time and you can achieve the requirements missing for the Parametric, E-mentor suggests you to do the estimate using both methodologies to verify and be <u>more confident</u> of the result.

Else If (A=no and P=no) then
Carry on the Detailed Methodology.
Analogy is not suitable for the reason: *Comment_A*
Parametric is not suitable for the reason: *Comment_P*

If you have the time and you can achieve the requirements missing for the Analogy and/or Parametric, E-mentor suggests you to do the estimate using them in order to verify and be more confident of the result.

Else If (A=yes And P=yes) then
You can use **Detailed, Analogy and Parametric Methodologies**. E-mentor suggests you create three cost estimates using the three methodologies. This will allow you to check the results and be more confident of the outcome.

If time is a constraint and you have to select one or two, e-mentor suggests you carry on the Detailed methodology and then if possible to choose between Analogy and Parametric bearing in mind:

- Targeting the accuracy to achieve (quality of data and resources):
  - The similarity with the previous project/product is really strong, better than the relevance with the historical data available → Analogy.
  - The relevance of historical data available is better than the similarity with the previous project/product →Parametric.
- If you have the required data/resources the Analogy Methodology will probably take less time than the Parametric Methodology. Detailed methodology will probably take a bit more time than Parametric and Analogy, but you will normally achieve better accuracies.

End if

Else If (D1=no) then

You should **not** carried out the **Detailed Methodology** as you do not have a clear picture about what are the materials, labour and equipment to be used, or the manufacturing process involved.

If (A=yes and P=yes) then
You can use **both Analogy and Parametric Methodologies**. E-mentor suggests you create two cost estimates using both methodologies. This will allow you to check the results and be more confident about the outcome
If time is a constraint and you have to select just one methodology your decision should bear in mind:

- Targeting the accuracy to achieve (quality of data and resources):
  - The **similarity** with the **previous project/product** is really strong, better than the relevance with the historical data available, then **Analogy** Methodology.
  - The relevance of the **historical data** available is better than the similarity with the previous project/product, then **Parametric** Methodology.

- If you have the required data/resources the Analogy Methodology will probably take less time than the Parametric Methodology.

Else If (A=no and P=yes) then
According to your current availability of data, resources and project phase you should carry on The **Parametric Methodology**.
The Analogy Methodology is not suitable for the reason: *Comment_A*

If you have the time and you can achieve the requirements missing for the Analogy Methodology, E-mentor suggests you to do the estimate using both methodologies to verify and be more confident of the result.

Else If (A=yes and P=no) then
According to your current availability of data, resources and project phase you should carry on the **Analogy Methodology**.
The Parametric Methodology is not suitable for the reason: *Comment_P*

If you have the time and you can achieve the requirements missing for the Parametric, E-mentor suggests you to do the estimate using both methodologies to verify and be more confident of the result.

Else If (A=no and P=no) then
You do **not** fulfil any of the **minimum requirements** to start the CE process using neither the Analogy not the Parametric Methodologies.
The requirement to start the Analogy is:
- *Comment_A*

The requirement to start the Parametric is:
- *Comment_P*

End if

Else If (D1=yes and D=no) then

The E-mentor suggests the **Detailed Methodology** as you will have to use it anyway in further estimates. Because you are not able to obtain all or some of the material, labour or/and equipment cost data you can use E-mentor information presented below. Using this data you may take account of the issue that you are not using the same grade of material or the same machine mode. Some certain level of inaccuracy will be accepted.

Materials	Labour		Equipment
	Countries	Industries	
aluminium magnesium steel titanium	china france uk	aero auto elec_equip_manf	cnc_lathe cnc_milling conventional_lathe conventional_milling horizontal_mc turning_centre

If (A=yes and P=yes) then
You can use **both Analogy and Parametric Methodologies**. E-mentor suggests you create two cost estimates using both methodologies. This will allow you to check the results and be more confident about the outcome
If time is a constraint and you have to select just one methodology your decision should bear in mind:

- Targeting the accuracy to achieve (quality of data and resources):
  - The **similarity** with the **previous project/product** is really strong, better than the relevance with the historical data available, then **Analogy** Methodology.
  - The relevance of the **historical data** available is better than the similarity with the previous project/product, then **Parametric** Methodology.

- If you have the required data/resources the Analogy Methodology will probably take less time than the Parametric Methodology.

Else If (A=no and P=yes) then

According to your current availability of data, resources and project phase you should carry on the **Parametric Methodology**.
The Analogy Methodology is not suitable for the reason: *Comment_A*

If you have the time and you can achieve the requirements missing for the Analogy Methodology, E-mentor suggests you to do the estimate using both methodologies to verify and be <u>more confident</u> of the result.

Else If (A=yes and P=no) then
According to your current availability of data, resources and project phase you should carry on the **Analogy Methodology**.
The Parametric Methodology is not suitable for the reason: *Comment_P*

If you have the time and you can achieve the requirements missing for the Parametric, E-mentor suggests you to do the estimate using both methodologies to verify and be <u>more confident</u> of the result.

Else If (A=no and P=no) then
You do **not** fulfil any of the **minimum requirements** to start the CE process using neither the Analogy and Parametric Methodologies.
The requirement to start the Analogy is:
- *Comment_A*
The requirement to start the Parametric is:
- *Comment_P*

End if
End if

Retrieve and make use of any cost estimate done in the Preliminary stage regarding this project.

ElseIf (final=yes) then

Print "E-mentor strongly recommends you to carry on the **Detailed Methodology** as you are in the Final stage of the project life cycle".

If (D1=yes) then

Go to do the second form.
If [QD1=yes and QD2=yes QD3=yes] then
D=yes
else If [QD3=(yes or some) and QD2=(yes or some) QD3=(yes or some)] then
D= yes1
else
D=no

End if

If (D=no) then
According to your answers you are not able to obtain all or some of the material, labour or/and equipment cost data.
E-mentor suggests you first try again to **find the cost data** you think you are **missing**.
If it is definitely not possible, presented below it is some of the data the E-mentor is able to provide you, at least as control values.

Materials	Labour		Equipment
	Countries	Industries	
aluminium magnesium			cnc_lathe cnc_milling

steel titanium	china france uk	aero auto elec_equip_ manf	conventional_lathe conventional_milling horizontal_mc turning_centre

Else If (D=yes) then
Carry on the Detailed Methodology.

Else If (D=yes1) then
Presented below is some of the data the E-mentor can provide. At this stage it is important to use as much known information as possible. Most of your material, labour and equipment cost should be known.

Materials	Labour		Equipment
	Countries	Industries	
aluminium magnesium steel titanium	china france uk	aero auto elec_equip_ manf	cnc_lathe cnc_milling conventional_lathe conventional_milling horizontal_mc turning_centre

End if

If (A=yes) then
If you have time the system recommends you do an Analogy Methodology to check the results. If you have done it in previous stages you should now retrieve it and review it to see if it can be improved in order to get better accuracy.
End if

If (P=yes) then
If you have times the system recommends you do a Parametric Methodology to check the results. If you have done it in previous stages you should now retrieve it and review it to see if it can be improved in order to get better accuracy.
End if

Retrieve and make use of any cost estimates done in the Preliminary and Intermediate stages regarding this project.

Else
You are probably **not** on the ***Final Stage*** as you should have a clear picture about what are the materials, labour and equipment to be used. Could you please reconsider the project level definition or redefine questions 1, 2, 3 and 8?

End If

End if

ANNEX G: CASE STUDY 2 – PROJECT LIFE CYCLE WING BOX RIBS

Sector: Aerospace
Order of estimated cost of the project: 250k £ (for the 2 wings)

Stage of the project life cycle	**Preliminary**	**Intermediate**	**Final**
	Was it with <10% project definition? Yes. Aprox. accuracy obtained: 21%	Was it between 10-40% of project definition? yes Aprox. accuracy obtained: 10%	Was it with >40% project definition? Yes Aprox. accuracy obtained: 2-5% (stage not achieved)
	There is a 11% difference of accuracy between the preliminary and intermediate cost estimating results. He expects there will be around 10% of difference between the accuracy of the intermediate and final stages (2 weeks ago finished the intermediate, is why he can not say the exact %)		
Characteristics	- Trade study: Best weight, materials, manufacturing concept, feasibility. - Does not know labour types and machines. - They use the parameters: weight and dimensions to create the parametric cost model.	Good concept design: - materials (theoretical conceptual BoM with Excel): - Conventional aluminium. - Aluminium- lithium (they follow 2 cost estimations for each material). The process is defined: - Identification of labour types. - Design engineers. - Programmers. - Stress engineers. - Manufacturing engineers. - Tool manufacturers. - Machining operators (4 types of machines) - Assembly operators. - Treatment operators. - Identification of equipment (4 types of machines). [For labour and equipments you just need the	Fully defined BoM (with a specific application, ex. CAD software, not with Excel like in Intermediate – Intermediate they do not use the CAD software because the design in no enough detailed). - Firm&Fixed (not subjected to change – production standard): Materials, dimensions, quantities, etc. - Clear picture about what is manufactured and what purchased or subcontract. - Available capacity and resources (human, equipment, buildings, etc.)

		rate per type of machine or labour: $/hour and you need the hours required to manufacture the product]. [All this data was collected in a Excel file]	
Methodology used	- Parametric model with weight and dimensions as cost drivers. - Analogy: with a previous plane model (A3). As they were not the manufacturers of the analogous (so they didn't have the information) they created a parametric model on to come up with the analogous product cost (A3). The result of the A3 parametric was used to create the analogy with the A5. [This is a particular case, it is not what more often occurs, usually you would do an analogy having the data from precious similar project] Tools that you use for the parametric and analogy creation? Just Excel. Why do you create 2 cost estimates with 2 different methodologies? To be more confident on the result (sanity test). The difference of accuracy between the 2 results was inferior to 10%.	Detailed (Using Excel spreadsheets)	Detailed (No use of Excel Spreadsheets. They will probably import data from the Excel spreadsheet created in the intermediate stage to a MRP/CAD system, on purpose built for manufacturing).
Outcome (use of the cost estimate)	- Preliminary design concept. - Authority to proceed with the aircraft (from customer point of view, the decision of making the airplane is accepted), although there is at this	- Outsourcing decision for the aircraft manufacturer (partners, suppliers, etc.) → Manufacturer get the job (this is the typical situation, although it can be possible that the selection supplier is already defined by any type	- Basis of strategic plan (external shareholders are interested in). - Resources plans: with the estimation you can do an estimation of the resources in terms of number of employees and

	stage not a clear picture about who will be the manufacturer. - Metal-aluminium rather than composites.	of contract). - Manufacturer Bid/tender for customer. - Although from customer point of view the authorization proceed is accepted there is reviewed and it could be possible (not often) to stop the project if the results are not in accordance of what was expected.	number of machines required. - Series Production: Production on a regular schedule (proper production, after all prototypes have been done)
Questions in the form	Q1=Q2=Q3=Q8=No Q4=Q5=Q6=Q7=Yes	Q1=Q2=Q3=Q4=Q5=Q6=Q7=Q8=QD1=QD2=QD3= Yes	Q1=Q2=Q3=Q4=Q5=Q6=Q7=Q8= QD1=QD2=QD3= Yes
		The information is available in both cases; this is why the answer to the questions is the same. However, the level of confidence in the definition of the information varies, in 2 ways: - Some new elements may have been considered. - The information for current elements may be more precise and accurate.	
Suggestion from the e-mentor	You can use **both Analogy and Parametric Methodologies**. E-mentor suggests you create two cost estimates using both methodologies. This will allow you to check the results and be more confident about the outcome. If time is a constraint and you have to select just one methodology your decision should bear in mind: - Targeting the accuracy to achieve (quality of data and resources): ------> The **similarity** with the **previous project/product** is really strong, better than the relevance with the historical data available, then **Analogy** Methodology. ------> The relevance of the **historical**	You can use **Detailed, Analogy and Parametric Methodologies** estimates. E-mentor suggests you to create three cost estimates using the three methodologies. This will allow you to check the results and be more confident about the outcome. If time is a constraint, and you have to select one or two, E-mentor suggests you to carry on the **Detailed** and then if possible to choose between Analogy and Parametric bearing in mind: - Targeting the accuracy to achieve (quality of data and resources): ------> The similarity with the previous project/product is really strong, better than the relevance with the historical data available, then Analogy. ------> The relevance of the historical data available is better than the similarity with the previous project/product, then Parametric.	E-mentor strongly recommends you carry on the **Detailed Methodology** as you are in the *Final Stage* of the project life cycle. Carry on **Detailed Methodology** If you have time we recommend you do an **Analogy** to check the results. If you have done it in previous stages you should now retrieve it and review it to see if it can be improved in order to get better accuracy. If you have time we recommend you do a **Parametric** to check the results. If you have done it in previous stages you should now retrieve it and review it to see if it can be improved in order to get better accuracy. Retrieve and make use of any cost

	data available is better than the similarity with the previous project/product, then **Parametric** Methodology. - If you have the required data and resources the Analogy methodology will probably take less time than the Parametric methodology.	- If you have the required data and resources the Analogy Methodology will probably take less time than the Parametric Methodology. Detailed will probably take a bit more time than Parametric and Analogy, but you will normally achieve better accuracies. Retrieve and make use of any cost estimate done in the Preliminary stage regarding this project.	estimate done in the Preliminary and Intermediate stages regarding this project.
Choice	Which would be your next step? - Redo the questions because you do not agree with the answers and you may think to change sth. (If yes explain what was wrong). - Selected methodology: “Analogy”. - Would you plan to do any other methodology after the first estimate? Which? “I would be interested in doing the Parametric”. “If I have got a the first idea that the cost of the wing box would be 300k £, because I am an expert in wings, then I would move straightforward to the Parametric. But in fact my idea of 300k £ is coming from an unconscious analogy done by myself”.	Which would be your next step? - Redo the questions because you do not agree with the answers and you may think to change sth. (If yes explain what was wrong). - Selected methodology: ”Detailed” - Would you plan to do any other methodology after the first estimate? Which? “from the creation of the analogy and parametric models in preliminary stage, the models has been updated with the new information available.” “This stage is not as much as time constrain than the Preliminary, where the customer expectations pressures you“.	Which would be your next step? - Redo the questions because you do not agree with the answers and you may think to change sth. (If yes explain what was wrong). - Selected methodology: “Detailed” - Would you plan to do any other methodology after the first estimate? Which? “Yes, I would do it. I would redefine the parametric and analogy cost model, as we are doing with the detailed, including if necessary new drivers and updating the current data to achieve better accuracies (as it is more reliable)”
Duration	2-3 weeks	8 weeks	On-going process (many iteractions) depending on when the first production is scheduled. In this case it will be around 20 months (2 years and 1/2).
	From after the 2-3 weeks to the intermediate stage it takes **1 year** (March 05 to March 06). During this year they did an ongoing review with new data available.		

ANNEX H: KNOWLEDGE AND SKILLS

Competence: **Learning curves**		
Knowledge (You know…)		**Skills** (You are able to…)
1- What are the contributing factors to learning and so cost reductions		1- Interpret historical data
2- The degree which different manufacturing processes are impacted by learning.		2- Recognise of trends and anomalies
3- Typical anomalies (description and how they are reflected in graphs)		3- Calculate historical line of best fit or identifying a possible LC that fits in your data.
4- Which is the peripheral knowledge (e.g. suppliers affecting learning curves)		4- Recognise the effects of peripheral knowledge
5- When to rely on learning curves		5- Apply learning curves
6- Types of learning curves.		
7- How to create learning curves		

Competence: **Cost Estimating Relationships**		
Knowledge (You know…)		**Skills** (You are able to…)
1- (about) CER development process.		1- Evaluate/interpret from data the relation between cost drivers and cost defined in the hypothesis and other missed in them.
2- Techniques (types) for developing and implementing CERs.		2- Ability to use Least-Square Best Fit (LSBF) techniques to derive CERs.
3- Limitations, errors and caveats of the use of LSBF and graphic method techniques.		3- Ability to use the graphical method to derive CERs.
4- When to use CER: strengths and weaknesses.		4- Generate linear and non-linear relationships.
5- What has to be considered to validate a CER.		5- Read and interpret graphics.
		6- Identify engineering solutions, determine a possible relationship around which data can be gathered and relationships determined.
		7- Conduct significance testing.
		8- Justify the validity of the CER selected.

Competence: **Data normalisation and calibration**	
Knowledge (You know…)	**Skills** (You are able to…)
1- (the) Purpose to normalise data. Problems with raw data.	1- Apply **inflation rates** to the historical data to use.
2- (the) Ways you normalise data.	2- Apply **currency exchanges** to the historical data.
3- (the) Purpose of calibration.	3- Apply **production rates** to the historical data.
4- (the) Achievements with calibration.	4- Model the Theoretical First Piece (T1) to eliminate the **quantity affect**. This is achieved by eliminating the Cost Improvement Curve effect.
	5- Separate **non-recurring** and **recurring costs** to the historical data.
	6- Adjust for **consistent scope.**
	7- Adjust for **anomalies**.
	8- Able to identify the companies technologies were a productivity advantage is evident.
	9- Able to identify third party productivity through supplier assessments.
	10- Able to manipulate the commercial model to reflect historical experience of the organisation regarding **Products.**
	11- Able to manipulate the commercial model to reflect accounting practices and **organisational** structure of the company.
	12- Use a calibrating tool.

Definition of the knowledge test questions based on the set of knowledge you are supposed to have. The questions have to be defined thinking on the set of knowledge is wanted to be proved they have.

Competence: Data Normalisation and Calibration	
Knowledge (You know…)	**Questions LC test**
1- (the) Purpose to normalise data. Problems with raw data.	7, 9
2- (the) Ways you normalise data.	2, 5, 8
3- (the) Purpose and steps of the calibration process	1, 4 and 10
4- (the) Achievements with calibration.	3, 6

Competence: **Cost Estimating Relationships**	
Knowledge (You know…)	**Questions CER test**
1- (about) CER development process.	1 and 2.2
2- Techniques (types) for developing and implementing CERs.	2, 3, 4, 6
3- Limitations, errors and caveats of the use of LSBF and graphic method techniques.	4, 8
4- When to use CER: strengths and weaknesses.	5 and 9
5- What has to be considered to validate a CER.	7

Competence: **Learning curves**	
Knowledge (You know…)	**Questions LC test**
1- What are the contributing factors to learning and so cost reductions	2, 3 and 9
2- The degree which different manufacturing processes are impacted by learning.	4
3- Typical anomalies (description and how they are reflected in graphs).	6
4- Which is the peripheral knowledge (e.g. suppliers or workforce affecting learning curves)	2, 3 and 6
5- When to rely on learning curves.	8
6- Types of learning curves.	7 and 10
7- How to create learning curves.	1, 5 and 10

ANNEX I: KNOWLEDGE TESTS

Learning curve

1. The line of best fit on plot of unit labour costs for a small assembly passes through the following points:

   i. T9 = $104.44
   ii. T20 = $86.61
   iii. T52 = $69.23
   iv. T95 = $60.10
   v. T104 = $58.84
   vi. T136 = $55.25
   vii. T149 = $54.08

   What is the slope of the learning curve? | 85 | %

2. The sales of Product xyz increase dramatically such that its manufacturing schedule has to be accelerated to meet the rising demand by offering overtime to the work force. The respective learning curve will:

   a. Become steeper
   b. Become less steep
   c. Remain the same

3. Product xyz continues to enjoy success in the market place with the result that production has to be further accelerated to meet the rising demand by introducing an extra shift. As a result the present work force will be increased through the recruitment of new personnel. The respective learning curve will:

   a. Become steeper
   b. Become less steep
   c. Remain the same

4. Compare **Figure 1** & **Figure 2**. Which of the following two assembly unit cost curves uses automation as part of the assembly process?

   a. Figure 1 because the capacity to learn is higher as much people are involved in the process.

b. Figure 2 because using automation you can get a bigger reduce of the costs per unit.
c. Figure 1 because during the first units there is more variability.
d. Figure 2 because as less people it is easy to learn.

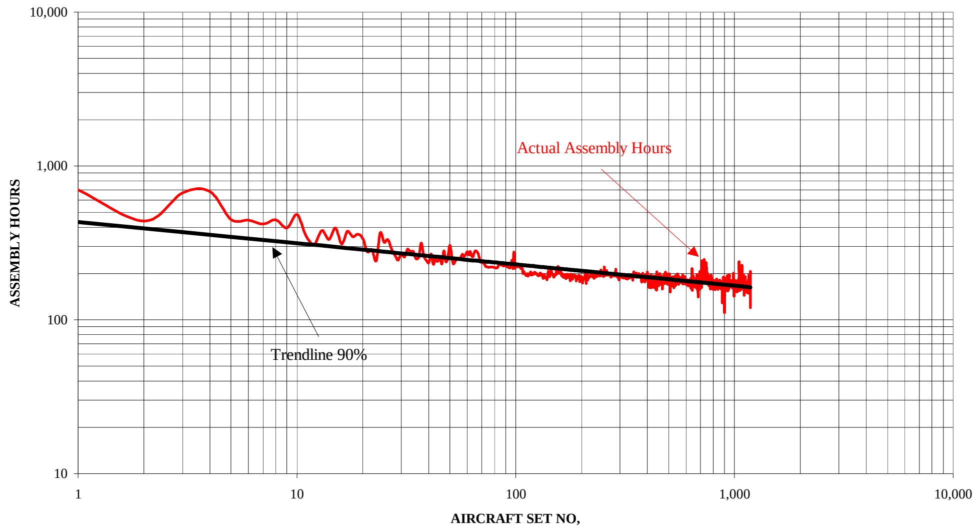


Figure 1

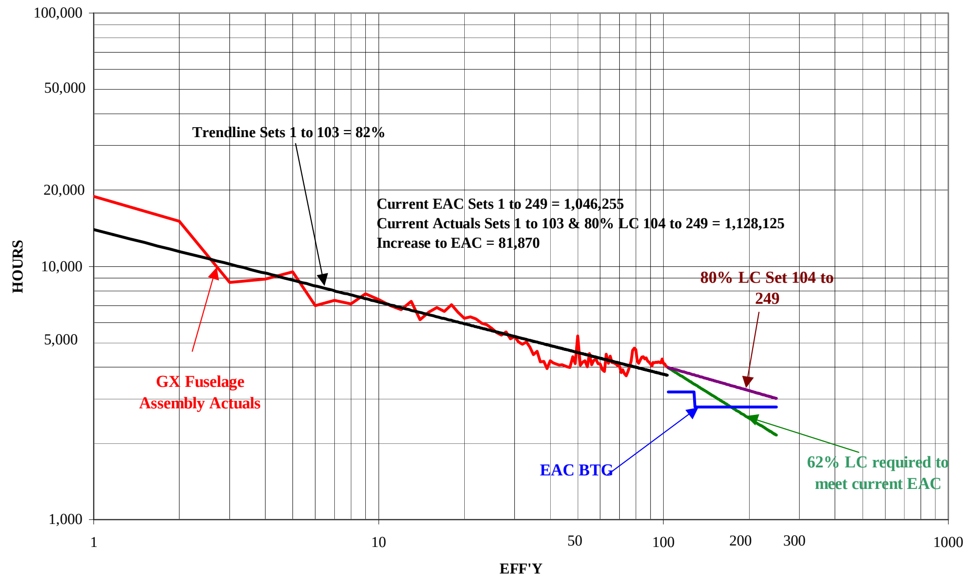


Figure 2

5. Using unit learning theory, estimate the cost in hours of the 48th unit if the cost of the 12th unit is 6400 hours and the learning curve slope is 75%. Round to the nearest hour.

[Source: *SCEA Certification Exam: Practice questions and study aid*]

Solution: 3600

6. Several events may have occurred at the start of the project represented by **Figure 1** and are listed below.

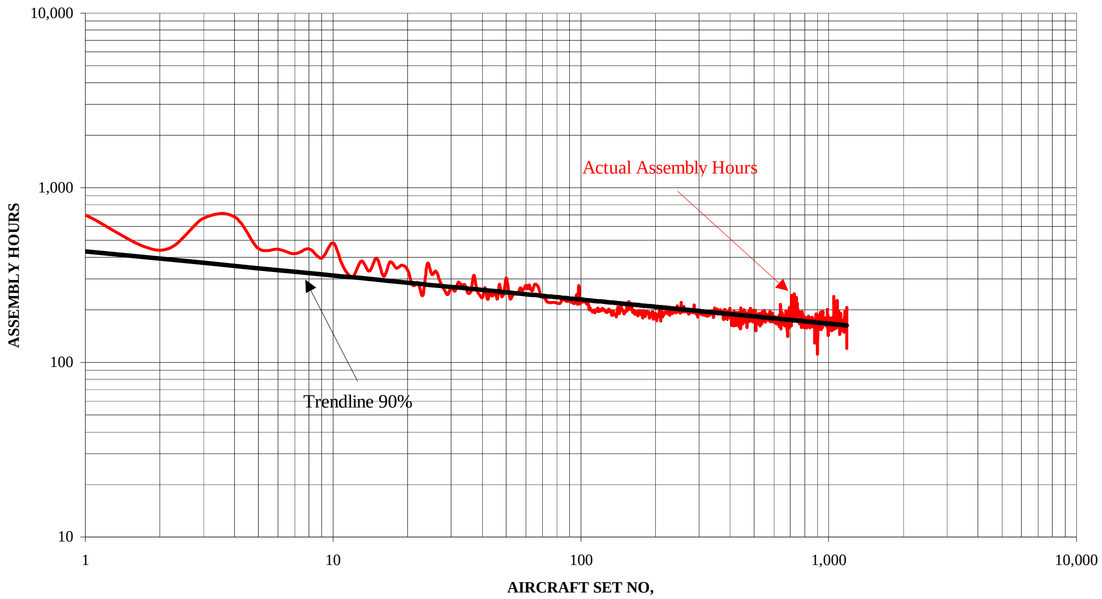


Figure 1

1. The work took place at a different industrial location
2. The cost management team failed to book the costs accurately
3. An engineering change was introduced
4. There was industrial action by the work force
5. There was a visit by the customer
6. There was a new machine introduced

Which combination of event/events is/are likely to be responsible for the increased costs of units 3 & 4:

a. 1, 2, 4 and 5
b. 1, 3, 4 and 6

c. 1, 3 and 6
d. All of them

7. Is it possible for an alternative trend line to be identified for **Figure 2**?
   a. Yes
   b. No

8. Which of the following terms it wouldn't be a learning curve objective (applications).
   a. Prepare bids for new products.
   b. Assessing loss of learning.
   c. Creating a company balance-sheet.
   d. Analysis and predict cost trends.

9. Which of the following terms it doesn't affect the learning curve definition.
   a. Improvement of tooling.
   b. Quality control.
   c. Engineering Changes to Assist production.
   d. Tool decommissioning.

10. Typical learning curve is defined with following exponential formula:

$$Y=AX^{b}$$

[True/False] A is the First Unit Hours (or constant currency per unit), so being X the unit number, when X values 1 then Y is the Hours/unit (or constant currency per unit).

Acknowledgement: International Society of Parametric Analysts (SCEA/ISPA) sample exam paper at www.ispa-cost.org and NASA (2002)

Cost Estimating Relationship

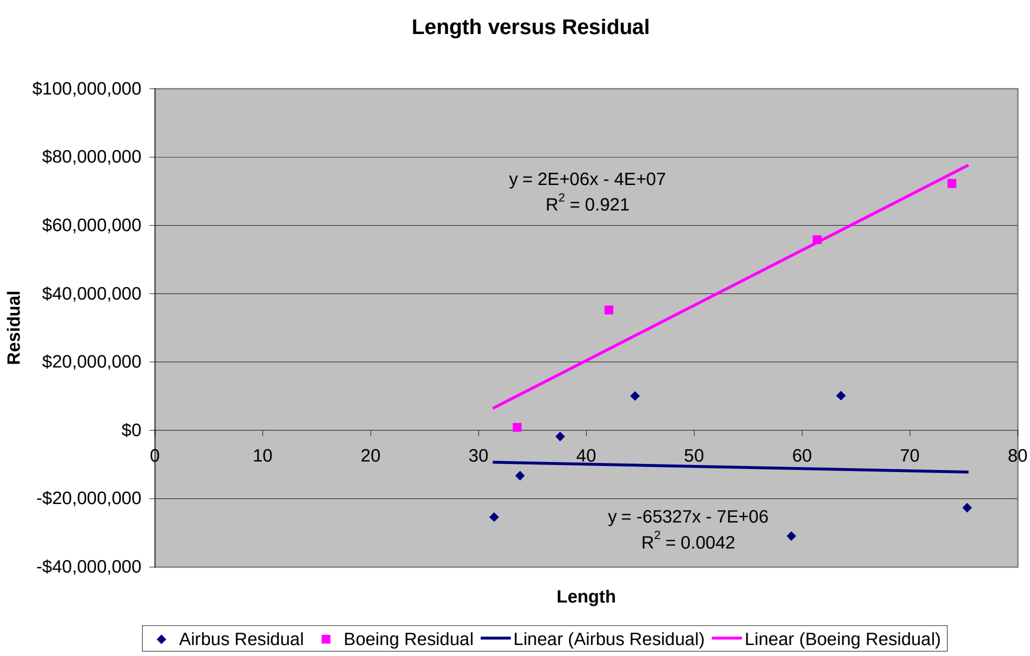
1. **[True/False]** A possible Cost Estimating Relationship would be:

$$PW = 0.63 \times Wt^{0.68} \times S^{1.21}$$

Where:
PW = Maximum Power in watts
Wt = Airframe unit weight in pounds
S = Maximum speed at best altitude in knots

(Modified from Source: FAA Life Cycle Cost Estimating Handbook)

2. Take a look at the following graph, which represents two cost estimating relationships (CERs) from Airbus and Boeing Residual Costs:



2.1 The slope of the Boeing residual curve is:

a. 2E+06
b. –4E+07
c. 0.921
d. –7E+06

2.2 Which of the processes have been used to establish the graph above?

a. Once you have the CER curve you place the historical data points in order to see if they are close to the curve.
b. Once you have the CER curve you guess which can be the possible relation between the length and the residual cost
c. You take the historical data values and you draw them into the graph, which are these points. With them you will find out the curve.
d. None of the previous statements.

3. A software reuse cost model developed by the Averbury Corporation uses the following equation to compute "equivalent" size of reused code as an input to the model. The equivalent size formula is:

ESLOC = SLOC x (0.02 x SU x UNFM + 0.4 x DM + 0.3 x CM + 0.3 x IM)

Where SLOC = source lines of code (of program being modified)
ESLOC = equivalent SLOC
SU = software understanding, a value between 0 and 20
UNFM = degree of unfamiliarity, a value between 0 and 1
DM = fraction of design to be modified
CM = fraction of code to be modified
IM = fraction of integration and test to be re-done

Averbury has a program of 10,000 SLOC they want to convert from COBOL to JAVA. The programmers have never used the program and the program is poorly documented so both software understanding and unfamiliarity should have maximum values. The program will have to be totally re-coded, re-integrated, and re-tested, and 50 per cent of the program will have to be re-designed. What should be the value for ESLOC?

a. 8,000 b. 8,040
c. 10,000 d. 12,000

4. **[True/False]** A Multiple Regression Analysis will get better accuracy than a Linear Regressions analysis because you are considering more variables depending on the cost.

Multiple Regression Analysis: $Y= a + b_1X_1 + \ldots + b_nX_n$

Linear Regression Analysis: $Y = a + bX$

5. **[True/False]** A CER may be used to forecast costs, or it may be used to cross check and estimate developed using another estimating technique.

For example, an analyst may have generated an estimate using a detailed approach and then used a CER, as a sanity check to test the reliability of the detailed approach.

6. The Least-Squares Best Fit (LSBF) regression methods can be used to create a CER that is:

a. a linear relationship
b. a logarithmic relationship
c. an exponential relationship
d. all of the above

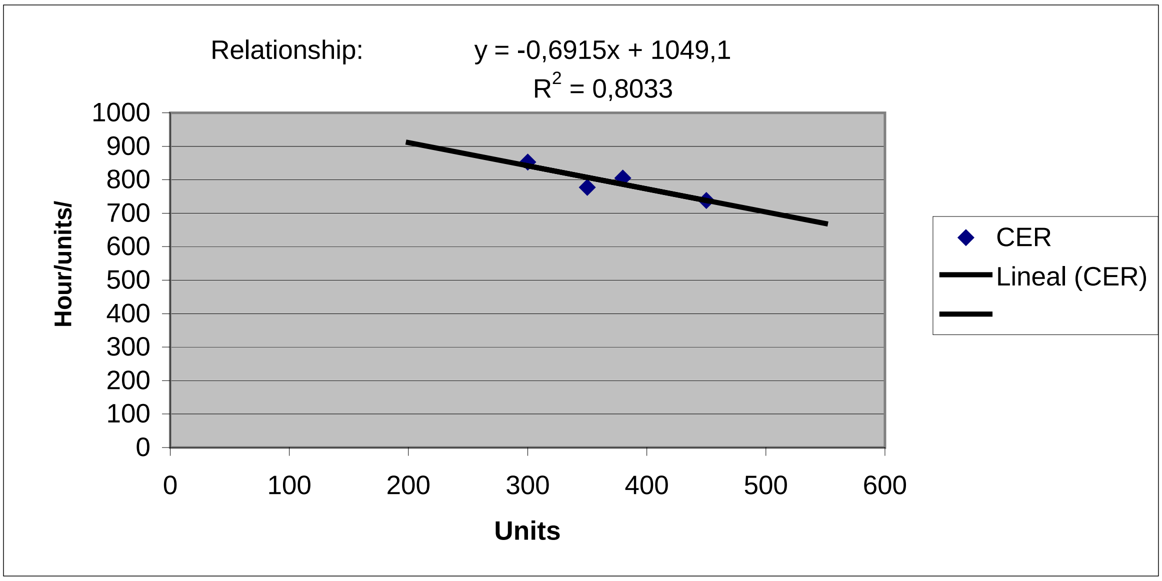
7. Which of the following statements is not correct:

a. The determination of acceptable criteria for a valid CER is based on discussions between the contractor and its customers.
b. Using the combination of the statistical indicators Standard Error (SE), Coefficient of Variation (CV) and the Adjusted R2, you will be able to validate or disqualify the cost estimation relationship (CER).
c. The Coefficient of Determination (unadjusted or adjusted, R2) can be used to assess overall CER goodness in that it indicates the "strength" of the relationship between X and Y.
d. The CER Degrees of Freedom, DoF, is a primary measure of CER reliability – a CER is only as reliable as the number (and quantity) its data points allow.

8. This is the data collected from the past after being normalised to estimate future average unit hours cost per unit.

Lot	**Units**	**Average hours per unit**
Lot 1	300	853 hours/unit
Lot 2	450	738 hours/unit
Lot 3	380	805 hours/unit
Lot 4	350	777 hours/unit

Using the following Relationship:



[True/False] There is more risk estimating the cost of a lot of 500 units than a lot of 375 units because the first one is not within the range of the previous data collection.

9. Which of the following statements is not correct:

   a. CER are quick and easy to use but sometimes are too simplistic to forecast costs.
   b. CER are quick and easy to use but if problems with the database may mean that a particular CER should not be used.
   c. As far as you have a considerable amount of data the validation of the CER will imply the validation of the data from the database.
   d. Use of valid CERs can reduce proposal time, evaluation, negotiation costs, and cycle time, particularly in regard to low=cost items that are time and cost intensive to estimate using other techniques.

Acknowledgement: International Society of Parametric Analysts (SCEA/ISPA) sample exam paper at www.ispa-cost.org and NASA (2002)

Data Normalisation and Calibration

1) **Multiple Choice:** Which one of the following steps is NOT part of calibration process:
   a) Define objects
   b) Data collection & analysis
   c) Model validation
   d) Print out of the estimate

2) **True or False:** Historical cost data should be adjusted for anomalies when it is not reasonable to expect these unusual costs to be present in the new projects.
   TRUE

3) **Numerical:** Once we have obtained a number of complexity values from our calibration run, what is the Mean value of the data sample below one would use to do a forward run?

   Item 1 = 4.381
   Item 2 = 4.179
   Item 3 = 3.999
   Item 4 = 4.496

   a. 3.999   b. 4.264
   c. 5.685   d. 17.055

4) **Multiple Choice:** Collection of cost data is considered critical to calibration. What data is not needed:

   a) Economic Conditions
   b) Currency
   c) Cost Unit
   d) Weight

5) **Numerical:** A historical project cost an organisation $75,000 (US) in 1993. The current exchange rate is $0.50 to £1. Compounded inflation between 1993 and now is 38%. What is the cost normalised to today's economic conditions in British Pounds (£)?

   a. £37,500   b. £57,500
   c. £103,500   d. £112,500

6) **True or False: "**When calibrating, an estimated cost is expected as an output from a commercial parametric model".
FALSE

7) An analyst has collected four production lots of manufacturing hour's data:

Lot	Total Hours	Units	Average hours per unit
Lot 1	256,000	300	853 hours/unit
Lot 2	332,000	450	738 hours/unit
Lot 3	361,760	380	952 hours/unit
Lot 4	207,000	300	690 hours/unit

True or False: Looking at the four lots above, Lot 3 should be further investigated as a possible anomaly due to the high number of Average Hours per Unit.

TRUE

8) **Multiple Choice:** Information in the following table represents a company's historical data and that the prospective system is similar to one built several years ago.

Parameter	Historical System	Planned System
Date of Fabrication	Jul 98 - Jun 00	Jul 03 - Dec 03
Production Quantity	500	750
Size - Weight	22 kg external case 5 kg int. chassis 8kg elec. parts	20 kg external case 5 kg int. chassis 10 kg elec. parts
Volume	1.00 m^3	0.75 m^3
Other Prog. Features	5% elec. Additional spare parts	5% elec. No spare parts

Modification of International Society of Parametric Analysts (ISPA)

The normalisation adjustments required are:

a) The inflation factors, the quantity difference, the rate of production effect, and the added elements in the original program (spare parts).
b) The inflation factors, the quantity difference, the size-weight difference and the volume difference.
c) The inflation factors, the rate of production effect, the volume difference and the added elements in the original program (spare parts).
d) None of the previous statements is right.

9) **Multiple Choice:** Which of the statements is *most* correct?

a) Raw materials and Engineering drawings generate recurring costs; Configuration management and Software development nonrecurring costs.
b) Raw materials and Configuration management generate recurring costs; Engineering drawings and Software development nonrecurring costs.
c) Raw materials and Software development generate recurring costs; Engineering drawings and Configuration management nonrecurring costs.
d) None of the previous statements are right.

10) **Multiple Choice:** Which of the following statements is *most* correct?

a) commercial models may sometimes be used to develop the basis of estimates if they have not been calibrated and validated
b) commercial models should be calibrated and validated before they are used to develop the basis of estimates
c) many commercial model vendors have already calibrated and validated models when they are sold off-the-shelf
d) auditors are not concerned with calibration and validation when evaluating commercial models

Acknowledgement: International Society of Parametric Analysts (SCEA/ISPA) sample exam paper at www.ispa-cost.org and NASA (2002)

ANNEX J: TRAINING METHODS

Training Method	Explanation	Real Online application (Moodle)	Learning Objective (KS) (the most relevant)
Lecture	Presentation of information, it can be printed or oral. Is best used to create understanding of a topic or to influence attitude. "Telling someone about something".	Application: - Reading documents (information) - Ppt lectures (with or without voice) - Glossary of terms. - Etc. Context: "the user has to go through the material but doesn't have to react after reading it".	-Declarative knowledge
Discussion method	Presentation of a topic and then establish an interaction among trainees or between trainer and trainee. The added communication gives it much greater power than lectures.	Two-way flow communication, the trainee active implication requires thinking about the content. "Discussion and questioning are beneficial because they enhance understanding". - Discussion in a chat. - Asynchronous contact by mailing. - Questions about the content of the lecture. - Quizzes about the content of the lecture.	- Declarative knowledge. - Procedural knowledge.
Demonstration	Stimulate the symbolic rehearsal. Visual display of how to do something or how something works. By simply watching the trainer demonstrate the competence, the learner is encouraged to think about doing it (even more is the trainee knows that then he/she will have to do it).	- Video which shows someone doing a cost estimate, either using the e-mentor or know. This is an option but it is not going to be a common training method, anyway.	-Procedural knowledge. - Skills.
CBT	There are many methods as: PI (programmed instruction), intelligence systems, interactive multimedia and virtual reality.		

	- **PI** and its evolution to **intelligent systems**: The training course is tailored according to the user needs, according to the answers propose one or other training material. In intelligence system (use of artificial intelligence) not only provides guidance and selects the appropriate level of instruction for the trainee, it also learns from its own processes, and based on that it improves the methodology for teaching the trainee.	Applicable previous the learning process when suggesting the training path, which are the suitable courses to go for according to a competency-based method. The intelligent system in not within the training material, so in that sense it has to be considered NA.	- Really efficient in all types ok knowledge and skills.
	Interactive multimedia: integrates text, video, graphics, photos, animation and sound to produce the complex training environment with which the trainee interacts [ex. take a medical history of a patient, conduct an examination and run lab tests. The student can select the type of examination, listen a sound and try to guess the problem and then establish the diagnosis].	NA	- Really efficient in all types ok knowledge and skills.
	- **Virtual reality**: placed in an artificial three-dimensional environment that simulates event and situations that might be experienced on the job	NA	- Really efficient in all types ok knowledge and skills.
Simulation/Games		The section simulation/Games is going to be understood like **exercises/assignments** in which the trainee has to develop competences related with the topic. Examples (try to decide in which group to put them and justify it between equipment simulators, business games, in-basket and behaviour): - (1) Do a statistical analysis with historical data provided and then the trainer will corrected. - (2) Carry on an own cost estimation using the e-mentor and submitted to the trainer. - (3) Questions like: - What would you do after… (asking for the process) - etc.	

	Equipment simulators: mechanical devises that require trainees to use the same procedures, movement, or decision processes they would use with equipment back on the job.	As the purpose is work with equipment, the kind of exercises could be using the e-mentor as a tool.	- Procedural knowledge and skills.
	Business games: simulations that attempt to represent the way an industry, company, or subunit of a company functions. From a description of a situation trainers are asked to make decisions about what to do. The game is based on relationships, rules, and principles derived from theory or research.	Are best for developing business decision-making skills and for exploring and solving complex problems. Few applicability for the current purpose, as the strategic knowledge is not a main focus of the project.	- Strategic knowledge (and procedural knowledge).
	In-basket technique: provide trainees with a packet of written information and requests (memos, messages, reports…) focus on the decision making.	Best suited to development of strategic knowledge used in making day-to-day decisions. Few applicability for the current purpose, as the strategic knowledge is not a main focus of the project.	- Strategic knowledge (and procedural knowledge).
	Case studies: trainee is usually presented with a story (written or videotaped), key elements, and problems of a real of imaginary organisation. There are usually some questions at the end of the case. Trainee must take certain judgments and identify possible solutions to the problem.	2 different approaches with cases studies can be done:	
		- Propose a case study as an assignment to be delivered and corrected for the mentor.	- Declarative and strategic knowledge. [focus more on “what to do” than “how to get it done”].
		- Take a case study as a best practise to go thought the e-mentor.	- Skills. Because the use of the case study is like an equipment simulation without feedback.

	Role play: enactment of a scenario in which each participant is given a part to act out. Trainees are provided with a description of the context and the problem they each face.	NA as the attitude change is not directly addressed in the training course, as explained in…	- Specially focus on attitude change.
	Behaviour modelling: the trainee observes the model behaviour (typically videotaped) and attempts to reproduce the behaviour. It differs from role plays and simulations because at first the trainee is told about what the desired skill level looks like.	NA- this method basically make sense in a face-to-face environment, so it is not going to be applied for the purpose.	
OJT	The use of more experienced and skilled employees to train less skilled and experienced employees. Process: The trainee observes the trainer performing job-related competences. The procedures and techniques are discussed before, during and after the demonstration. Then the trainee starts the performance. The trainer will provide guidance and feedback. The trainee is gradually receiving more and more of the job until he can do it entirely.	I think is NA for the training side. (but we can think about linking it in someway to the e-mentor)	The primary focus of OJT is skill development, although the acquisition of knowledge is quite good, specially the procedural.

Source: (Blanchard and Tracker, 2004)

ANNEX K: E-COURSES

1- Fundamental Skills and Knowledge of Cost Engineering	2- Quantitative Analysis Techniques	3- The estimating process
Table of Content 1. Basic Engineering Economics 2. Applied Engineering Economics 3. Contracting Fundamentals for Cost Engineers 4. Conceptual Cost Engineering 5. Detailed Cost Estimating 6. Statistics and Probability for Cost Engineers 7. Forecasting Applications for Cost Engineering 8. Operating and Manufacturing Cost Engineering 9. Basic Business and Finance for Cost Engineering 10. Project Management Basics 11. Constructability and Value Engineering 12. Planning and Scheduling 13. Project Control Basics 14. Productivity and Quality Improvement 15. Computer Basics for the Cost Engineer Course Review Iowa State University (http://www.ucs.iastate.edu/costengr1.htm, 08-06-2006) – Exact course	**Table of Content** 1. Basic Statistics Describing Central Tendency 1.1. The Arithmetic Mean 1.2. The Median 1.2. The mode 2. Sampling 2.1. Determining if Sampling is Appropriate 2.2. Selecting the Sample 2.3. Analyzing the Sample and Applying Findings 3. Regression Analysis 3.1. Regression Analysis Concepts 3.2. Evaluating the Performance of the Regression Equation 3.3. Advanced Topics in Regression Analysis 3.4. Uses of Regressions Analysis 4. Learning (improvement) Curves Uses of Learning (Improvement) Curves Developing and Analysing Improvement Curves Note on Computer Models http://fast.faa.gov/pricing/98-30C15.htm 14/06/06 Part of the complete course	**Table of Content** 1. Fundamentals of Project Cost Estimating 1.1. Common categories of cost 1.2. Roles of project cost estimates 1.3. Types of estimates 1.4. Areas of uncertainty affecting cost estimates 2. Projects 2.1. Definitions 2.2. Project and product life cycles 2.3. Requirements/needs assessment 2.4. The work breakdown structure (WBS) 3. The Estimating Process 3.1. Common categories of cost 3.2. Roles of project cost estimates 3.3. Areas of uncertainty affecting cost estimates 3.4. Types of costs throughout the lifecycle 3.5. The process ▪ Rules and assumptions ▪ Data collection ▪ Select methodology ▪ Estimate, check, review, and report ▪ Accuracy and contingency 3.6. Process for methodologies: ▪ Detailed ▪ Parametric ▪ Analogy ▪ Activity based costing (ABC) http://www.esi-intl.com/Register/course.asp?coursecode=GCP-CMB (14/06/06) – Part of the complete course

COMPETENCES (CE process)	1	2	3	4
1Concept of cost estimating & terminology	X (1)	-	X (1)	-
2Cost engineering/estimating methodologies	X (1)	-	X (1,2)	-
3Data normalisation and calibration	-	-	-	X (1,2,3)
4Breaking down the project	-	-	X (1,2,3)	-
5Documentation and data management	X (1)	-	X (1,2)	-
6Drawing and specification reading and analysis	-	-	-	-
7Industry and general manufacturing knowledge	-	-	-	-
8Estimate requirement definition (CARD)	-	-	X (1,2,3)	-
9Learning curves (cost improvement slope)	X (1,2)	X (1,2,3)	-	X (1,2,3)
11Basic mathematical, statistics & analytical skills	X (1,2)	X (1,2,3)	-	X (3)
12User level in related software applications	X (1,2,3)	-	-	-
13Basic Finance and accounting concepts	X (1,2,3)	-	-	-
14Risk evaluation and analysis	-	-	-	-
29Audit	-	-	-	-
15Detailed process	X (1,2,3)	-	X (1)	-
16Data collection – (Material, Labour, Equipment)	X (1,2)	-	X (1,2,3)	-
17Product specific manufacturing process	-	-	-	-
18Detailed cost modelling	X (1,2,3)	-	-	-
19Estimating allowances	-	-	X (1)	-
20Analogy process	-	-	X (1)	-
21Data collection (Design, Manufacturing, Cost, etc.) of strongly similar products.	-	-	X (1)	-
22Development of cost factors	-	-	-	-
23Parametric process	X (1,2)	-	X (1)	X (1,2,3)
24Definition of hypothesis	-	-	-	X (1,2,3)
25Data collection of historical data (manufacturing, design, cost, etc.)	-	-	X (1)	X (1,2,3)
26Statistical analysis	-	X (1,2,3)	-	X(2,3)
27Cost Estimating Relationships	-	-	-	X (1,2,3)
28Parametric cost modelling	-	-	-	X (1,2,3)

ANNEX L: CE PROCESS IN SCEA AND NASA

CE PROCESS AT **NASA:**

1. Receive Customer Request/Understand the Program
2. Define Work Breakdown Structure
3. Obtain or Prepare Cost Analysis Requirements Description (CARD)
4. Develop Ground Rules and Assumptions (GR&A)
5. Select Cost Estimating Methodologies
6. Select/Construct Cost Model
7. Identify Data Required, Data Sources, Obtain Data, Normalize Data
8. Populate Model and Calculate Cost
9. Develop Cost Range and Risk Reserves
10. Document the Cost Analysis
11. Present/Brief Results
12. Update Cost Estimates

CE PROCESS AT **SCEA:**

[Step 1] Define and plan the work to be done in as much detail as possible. This step includes determining the purpose, scope, and time Constraints for the Estimate, establishing an Estimating team, and analyzing the details of the work to be done, and the kinds and quantities of materials, parts, and equipment required.

[Step 2] Identify the cost elements or cost generating functional areas (i.e., engineering, manufacturing, procurement, etc.), which will be required to do the work defined in Step 1.

[Step 3] Schedule by time the work and effort defined and identified in Steps 1 and 2.

[Step 4] Select appropriate Cost Estimating Methodologies for each cost element, and estimate the man-hours, material costs, and other cost generating variables, as well as the elapsed time required to perform each detail of the work.

[Step 5] Estimate the costing rates and factors for the work to be done.

[Step 6] Apply the costing rates and factors to individual cost elements to establish total costs.

[Step 7] Evaluate the costs estimated so far. This step includes the application of alternative, secondary methodologies to cost drivers, preparation of an independent cost estimate, if desired, making any adjustments to the estimate that are required, or requested resulting from the review and analysis, and the application of desired profit, other cost factors and pro-rations or additions, to establish the final cost estimate.

[Step 8] Present the estimate to management for submittal to the customer.

[Step 9] Finish documenting the rationale, methodology, and supporting information utilized for the estimate.

[Step 10] Support source selection, negotiation, fact-finding, and/or audits, and update the estimate, as required.

ANNEX M: HELP FILES

HELP DATA NORMALIZATION AND CALIBRATION

The basic estimating methodologies (analogy, catalogue prices, extrapolation, factors/ratios, grassroots and parametric) are all data-driven. To use any of these methodologies, credible and timely data inputs are required. If data required for a specific approach is not available, then that methodology cannot be used. [Parametric Cost Estimating Handbook]

Data may be gathered from different sources and with different characteristics. In order to be compared it needs to be adjusted to similar concepts such as currency, year of data, same type of cost (e.g. recurring and non-recurring), learning achievements due to different range of production, etc.

[Parametric Cost Estimating Handbook] presents the normalization process description, which is not intended to be all inclusive.

Normalizing Cost Data
Making Units/Elements of Cost Consistent
Making Year of Economics Consistent

Normalizing The Size Data
Weight and Density Comparisons
Weight Contingency Application
Percent Electronics

Normalizing Products By Mission Application
Grouping Vehicles by Complexity
Calibrating Like Vehicles

Normalizing End Terms For Homogeneity
Account for Absent Cost Items
Removing Inapplicable Cost Items

Normalizing Recurring/Non-Recurring Cost
Prime Contractors' Estimates
Time Phased Costs
Flight-Article Equivalent Units

Normalizing State-Of-Development Variables
Mission Uniqueness
Product Uniqueness

Normalizing Environments (Platform):
Manned Space
Unmanned Space
Aerospace
Shipboard
Commercial

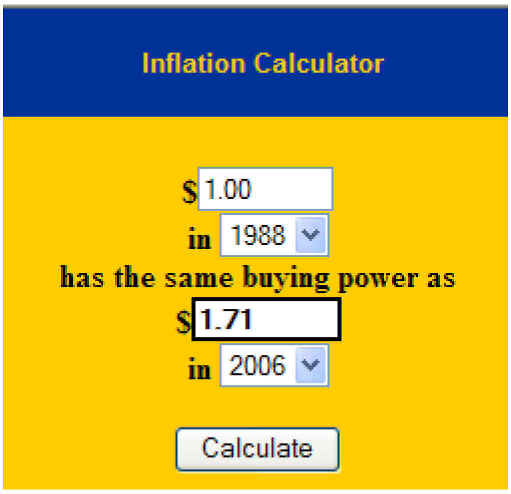
Following is presented typical adjustments to be addressed: Inflation, Consistent Scope, Anomalies, Improved Technology, Currency, Learning Curve and Production Rate.

Inflation [NASA, 2002]

Through escalation, inflation adjusts costs to reflect the decrease in the purchasing power of money. The inflation factor is the "multiplier" used to account for the change in price of a product or service over time. Escalation factor (or weighted inflation) is the "multiplier" used to account for inflation plus the normal occurrence of allocating money in one year and it being spent over a number of years.

“General inflation factors are almost certainly not appropriate to most situations. Ideally, the analyst will have a good index of costs which is specific to the industry and will use labour cost adjustments specific to his/her company”. [Parametric Cost Estimating Handbook]

Example to see how to calculate it:



(http://data.bls.gov/cgi-bin/cpicalc.pll, 17/07/2006. Source: U.S Department of Labor)

How much it would cost in the year 2006 an item bought in 1988 that costs $1000? You have to apply the inflation multiplier. According to the calculator provided by the U.S Department of Labor:

$$\$1000 * 1.71 = \$1710$$

The cost in the year 2006 would be $1710.

Consistent Scope [Parametric Cost Estimating Handbook]

Adjustments are appropriate for differences in program or product scope between the historical data and the estimate being made. For example, if the systems engineering department made a comparison of five similar programs and then realized that only two of the five had design to cost (DTC) requirements. To normalize the data, the DTC hours were deleted from the two programs to create a consistent systems scope and definition for CER development.

Anomalies [Parametric Cost Estimating Handbook]

Historical cost data should be adjusted for anomalies (unusual events), prior to CER analysis, when it is not reasonable to expect these unusual costs to be present in the new projects. The adjustments and judgments used in preparing the historical data for analysis should be fully documented. For example, a comparison has been made to compare the development test program from five similar programs and then certain observations are made (from history and interviews) that one of the programs experienced a major test failure (e.g., qualification, ground test, flight test). Considerable amounts of labour resources were required to fact find and then determine the root cause of and develop an action plan for a solution. Should the hours be left in or deleted?

Improved Technology [Parametric Cost Estimating Handbook]

Cost changes, due to changes in technology, are a matter of judgment and analysis. All bases for such adjustments should be documented and disclosed. For example, electronic circuitry was originally designed with discreet components, but now the electronics are ASIC technology. A hardware enclosure once was made from aluminium and now is made, for weight constraints, of magnesium. What is the impact on the hours? Perfect historical data may not exist, but judgment and analysis should supply reasonable results.
For example, suppose there are four production (manufacturing hours) lots of data that look like this:

Lot 1 256,000 853 hours/unit

Lot 2 332,000 738 hours/unit

Lot 3 361,760 952 hours/unit

Lot 4 207,000 690 hours/unit

Clearly, Lot 3's history should be investigated. It is not acceptable to merely "throw out" Lot 3 and work with the other three lots. A careful analysis should be performed on the data to determine why it behaved the way it did. There may have been a strike, or possibly an unusual and serious engineering problem impacted production costs. In any event, careful analysis is important.

Currency

Data has to be brought down into a constant currency using currency exchanges.
Example:

	British Pounds	Polish Zloty	Euro
Car cost (year: 2002)	20500	X1	X2

Going to check the currency exchanges from British Pounds to US Dollars and Euros for year 2002,

1 British Pound = 1.63372 Euro
1 British Pound = 5.79660 Polish Zloty

(Currency exchange on date 01/01/2002, http://www.oanda.com/convert/classic, 12/07/2006)

x1= 20500 * 1.63372 = 33491,26 Euros

x2= 20500 * 5.79660 **=** 118830,3 Zloties

Learning Curve [Parametric Cost Estimating Handbook]

The Learning Curve should be used only when learning/improvement is present (Jose Rios, 2005)

Factors that contribute to Learning Curve existence are listed as following according to Bombardier (2006):

<u>Component Contribution</u>

34%	Improvement to tooling
22%	Engineering Change to assist production
22%	Shop Learning
11%	Manufacturing Control
6%	Quality Control
5%	Manufacturing cost improvement

The learning curve as originally conceived analyses labour hours over successive production units of a manufactured item. The curve is defined by the following equation:

Hours/Unit = First Unit Hours * U^b
or
Fixed Year Cost/Unit = First Unit Cost * U^b

Where:
U = Unit number
b = Log(Slope of the LC)/Log(2)

In parametric models, the learning curve is often used to analyze the direct cost of successively manufactured units. Direct Cost equals the cost of both touch labour and direct materials - in fixed year dollars. Sometimes this may be called an improvement curve. The slope is calculated using hours or constant year dollars.

Slopes of the Learning Curve (LC)	
Criteria 1:	Criteria 2 (Cost Estimator's Reference manual):
75% hand assembly/25% machining = 80%	1. Aerospace 85%
50% hand assembly/50% machining = 85%	2. Shipbuilding 80-85%
25% hand assembly/75% machining = 90%	3. Complex machine tools for new models 75-85%
	4. Repetitive electronics manufacturing 90-95%``
	5. Repetitive machining or punch-press operations 90-95%
	6. repetitive electrical operations 75-85%
	7. Repetitive welding operations 90%
	8. Raw materials 93-96%
	9. Purchased Parts 85-88%

Source: [NASA Cost Estimating Handbook]

E.g. Characteristics:

- Cost of the first unit= 16 Euros
- Repetitive electronic manufacturing → We will take 90% from table x → Slope of LC = 0.9
- Production of 2000 units.

Fixed Year Cost/Unit = 16 * $2000^{[Log(0,9/Log(2))]}$ = **5,0391 Euros/Unit**

After 2000 units of production the unit cost would be 5,0391 Euros.

Production Rate [Parametric Cost Estimating Handbook]

Production rate effects (changes in production rate, i.e., units/months) can be calculated in various ways. For example, by adding another term to the learning or improvement curve equation we would obtain:
Hours/Unit = $U^b * R^r$
or,
Fixed Yr. $/Unit First Unit $ * $U^b * R^r$
Where:
U = Unit number
b = Learning curve slope
R = Production rate
r = Production rate curve slope
The net effect of adding the production rate effect equation (R^r) is to adjust First Unit $ for rate. The equation will also yield a different "b" value.
Rate effect may be ignored or can be treated in different ways in different models. If possible, rate effects should be derived from historical data program behavior patterns observed as production rates change while holding the learning curve constant.
The rate effect can vary considerably depending on what was required to effect the change. For example, were new facilities required or did the change involve only a change in manpower or overtime?

Two Illustrations of Typical Data Normalization Problems

Illustration 1

You plan to do a parametric estimate of a system using some company history. The system under investigation is similar to a system built several years ago. The two systems compare as follows:

Parameter	Historical System	Prospective System
Date of Fabrication	Jul 89-Jun 91	Jul 95-Dec 95
Production Quantity	500	750
Size- Weight	22 kg. external case	20 kg. external case
	5 kg. int. chassis	5 kg. int. chassis
	8kg. of elec. parts	10 kg. elec. parts
Volume	1 m^3	0.75 m^3

	12.l x ll.5 x l2.5	8 x 10 x l6.2
Other Program Features	Manual of operations included	Minor changes to manual
	5% Elec. parts as spares	

Normalization:

In this instance, we would require adjusting for inflation factors, the quantity difference, the rate of production effect and the added elements in the original program (the spare parts and manual). The analyst should be careful normalizing these data. General inflation factors are almost certainly not appropriate to most situations. Ideally, the analyst will have a good index of costs which is specific to the industry and will use labour cost adjustments specific to his/her company. The quantity and rate adjustments will have to consider the quantity effects on the company's vendors and the ratio of overhead and setup to the total production cost. Likewise, with rate factors each labour element will have to be examined to determine how strongly the rate affects labour costs. On the other hand, the physical parameters do not suggest that significant adjustments or normalization's are required.
The first order normalization of the historic data would consist of:
Material escalation using industry or company material cost history.
Labour escalation using company history.
Material quantity price breaks using company history.
Possible production rate effects on touch labour (if any) and unit overhead costs.
Because both cases are single lot batches, and are within a factor of two in quantity, only a small learning curve or production rate adjustment likely is required.

Illustration 2

You are considering building some equipment for the first time. Relevant labor effort history relates to equipment built some time ago but reliable data is only available from the third lot, beginning at unit 250. The available history indicates a cost improvement curve on this history of 95% from the fourth lot on. This history is considered the best available.
Normalization here requires two steps. Unless you believe the early lot cost improvement curve is the same as the historical lot improvement curve of the later lots (unlikely), you will need to identify cost improvement curves which may be applicable. These data points will have to be normalized to some common condition and the resulting improvement curve applied to the case at hand. Suppose the relevant history is as follows:

Case	Date	Quantity.	Lots	Rate of Prod.	Improvement Curve
Case A	1985-87	1000	6	5 per day	90%
Case B	1990	400	2	2 per day	83%
Case C	1991	350	3	1.9 per day	91%
Case D	1993-95	5000	10	7 per day	93%

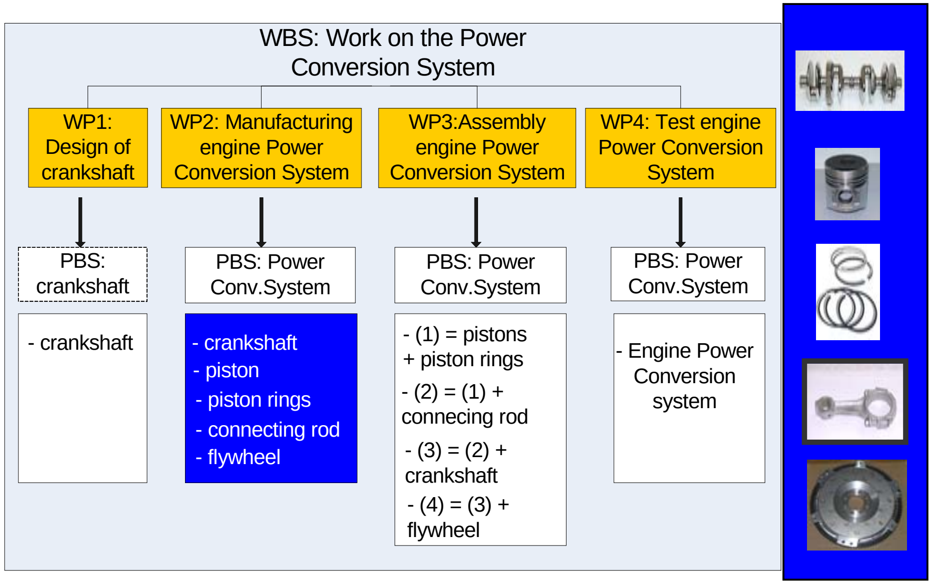
Clearly, the selection of an appropriate learning curve will be a judgment call that will depend upon the case at hand and how it relates to the historical data. For instance, there is some suggestion that the fewer the number of lots, the steeper the learning curve. How does the production rate and quantity match the data? In this situation, the analyst could break up the production history and examine the relationship of the learning curve to the lot sequence, the quantity, and the production rate. The date may reflect the technology involved and any historical comparisons will have to include the impact of relevant technology.

WORK BREAKDOWN STRUCTURE (WBS):

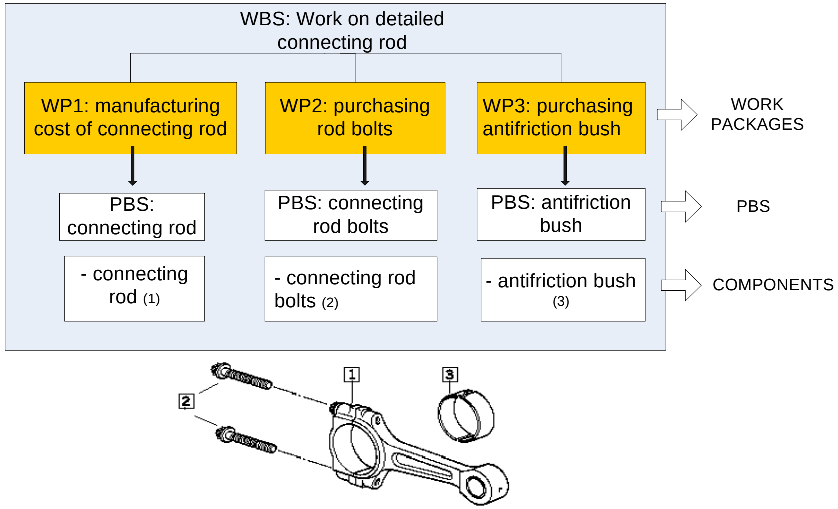
A technique for representing all the components, software, services and data contained in the project scope statement. It establishes a hierarchical structure or product oriented "family tree" of elements. It is used to organize, define and graphically display all the work items or work packages to be done to accomplish the project's objectives.

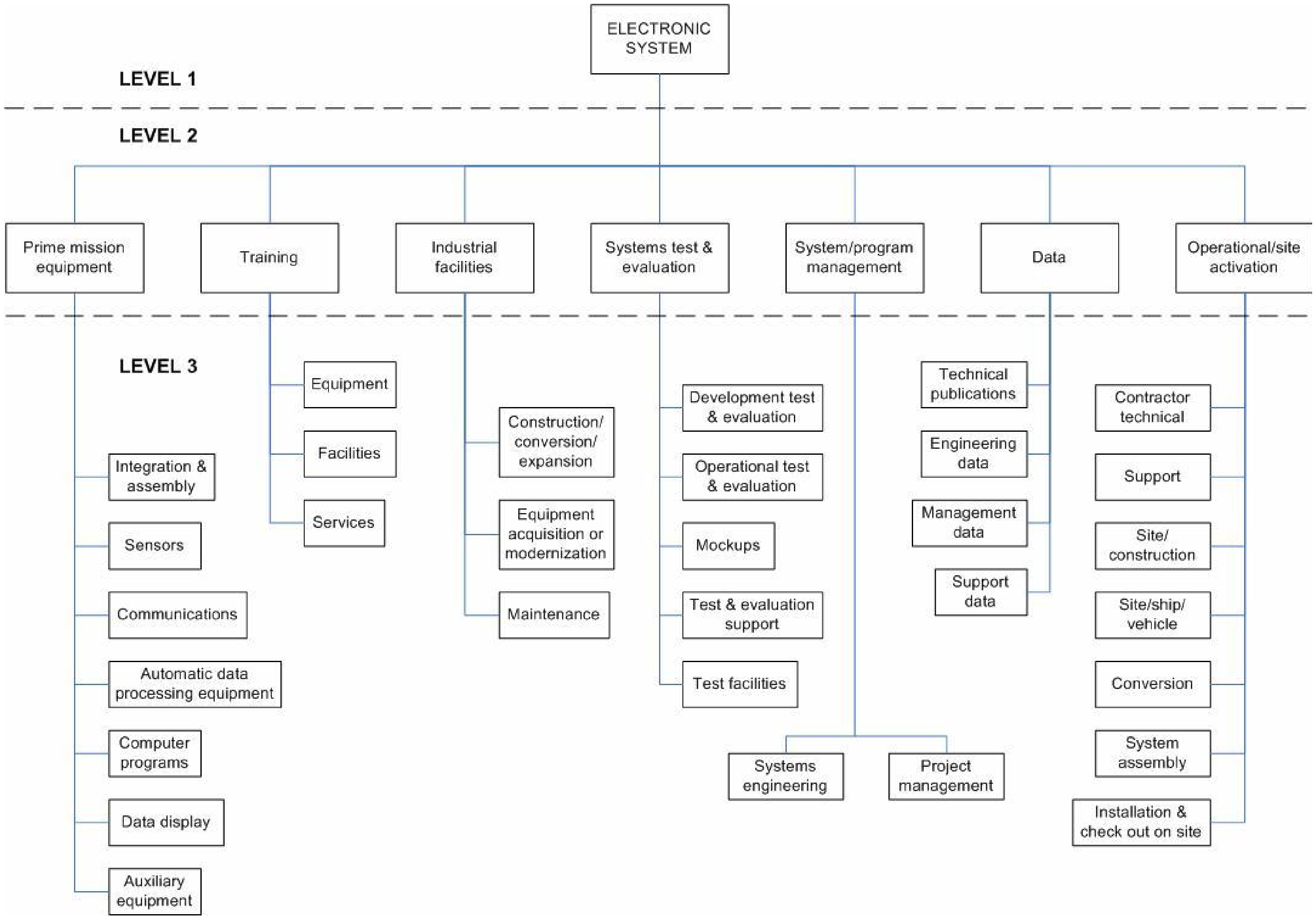
[NASA Cost Estimating Handbook 2004]

a) WBS for the Work on the Power Conversion System



b) WBS for the work on a connection rd





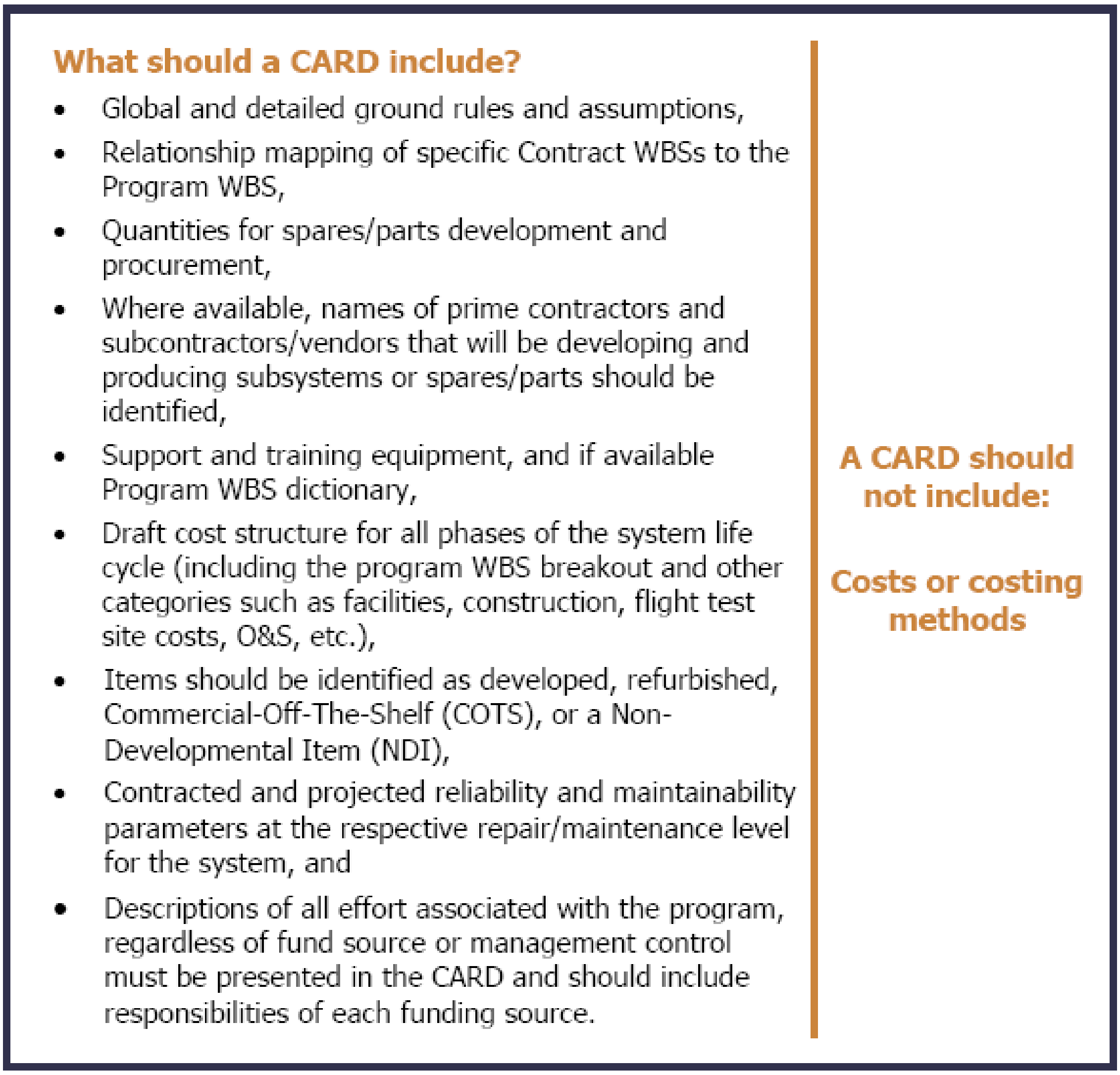
ELECTRONIC SYSTEM
LEVEL 1
LEVEL 2
Prime mission equipment
Training
Industrial facilities
Systems test & evaluation
System/program management
Data
Operational/site activation
LEVEL 3
Integration & assembly
Sensors
Communications
Automatic data processing equipment
Computer programs
Data display
Auxiliary equipment
Equipment
Facilities
Services
Construction/ conversion/ expansion
Equipment acquisition or modernization
Maintenance
Development test & evaluation
Operational test & evaluation
Mockups
Test & evaluation support
Test facilities
Systems engineering
Project management
Technical publications
Engineering data
Management data
Support data
Contractor technical
Support
Site/ construction
Site/ship/ vehicle
Conversion
System assembly
Installation & check out on site

WBS example (table type representation):

Example related to the construction of a new assembly line. Source: Ref [2].

LEVEL 1	LEVEL 2
1 Process design	
	1.1 Develop list of assembly operations
	1.2 Estimate assembly time for each operation
	1.3 Assignment of operations to workstations
	1.4 Design of equipment required at each station
2 Capacity planning	
	2.1 Forecast of future demand
	2.2 Estimates of required assembly rates
	2.3 Design of equipment required at each station
	2.4 Estimate of labor requirements
3 Material handling	
	3.1 Design of line layout
	3.2 Selection of material handling equipment
	3.3 Integration design for the material handling system
4 Facilities planning	
	4.1 Determination of space requirements
	4.2 Analysis of energy requirements
	4.3 Temperature and humidity analysis
	4.4 Facility and integration design for the whole line

ESTIMATE REQUIREMENT DESCRIPTION (CARD)



Source: (NASA, 2002)