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A prediction system for assessing customer affordability of whole life cycle cost in defence industry

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Abstract The manufacturing, delivery and support of service contracts in defence aerospace industry require a high financial investment. It is essential that the customer has the financial ability to procure and support the contract from the conceptual and manufacturing phase to the end of the project given the budget constraints. The aim of this paper is to identify the factors that affect customer affordability of defence contracts and develop a customer affordability assessment framework which is implemented as a software prototype system. Two major quantitative factors and twelve qualitative factors were identified, out which seven factors (identified as the major factors) were included within the customer affordability system. Following the identification of factors and development of measures for each, suggested actions to improve customer affordability were also proposed. The research methodology combined both case study and literature review approach with industrial collaboration in the customer affordability system development. The customer affordability system was validated through collaboration with industrial partners and a case study from defence sector and the results showed that the customer affordability system was capable of providing a good assessment of customer affordability.

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Introduction

The nature of the defence sector differs from or other sectors in a number of ways. One of them is in the fewer number of players, for example the UK Ministry of Defence (MoD) is the main defence customer within the UK, surrounded by many contractors. Another difference is the lifecycle of the contracts which typically runs through the Concept, Assessment, Demonstration, Manufacture, In-service and Disposal (CADMID) cycle of large complex systems and equipment for a duration which could be between 5 and 40 years or more. Different contracting approaches are employed within the defence industry such as traditional, spares and repairs, availability and capability contracts. The move towards availability contracts with the duration described above, necessitates the implementation of robust cost estimating techniques to assess the through life cost (whole life cost) of the contract. Alongside through life cost assessment, it is important to consider the budget available to the defence customer. The UK MoD is increasingly being faced with budget constraints (Asteris 1994; Gray 2009) which suggests the need for a proper customer affordability assessment of defence contracts prior to contract award. Failure to perform a proper estimate of defence contracts and assess this against available budget has lead to some project cost overrun by almost 40% or more and late project delivery of about 80% or longer (Gray 2009). The effect of uncertainty in both cost estimate and budget provision is also a factor that disrupts the successful execution of defence projects. This shows that there is a need for better cost estimating as well as better customer affordability assessment processes, tools and skills for the defence sector. In literature, tools and techniques for improving process such as general manufacturing, food manufacturing, assembly and disassembly etc. have been developed, but none has been indentified to assess the affordability of defence contracts (Chang et al. 2008; Chiu et al. 2003; Valle et al. 2010). While the current practice of customer affordability assessment in the defence environment is simply to focus on the quantitative factors by checking the cost against the budget, this does not result in a holistic assessment because there are many qualitative factors that affect defence contracts. This paper reviews factors affecting the customer affordability of UK defence contracts which are qualitative and quantitative and employs them in developing a customer affordability assessment framework which is implemented as a software prototype system. The customer affordability system is validated with a case study from the defence sector.

The remainder of the paper is presented as follows: Section "Related research" provides related research to approaches in defence procurement and affordability across different sectors while Section"Methodology" explains the methodology employed in the paper as well as the framework. Section "Development of customer affordability assessment system" explains the customer affordability system, the input for the system namely; the customer affordability factors affecting and uncertainty consideration. Section "System validation" presents the validation approach for the system with industrial partner and the application of the system to real-life case study while the discussion is provided in Section "Discussions and conclusions".

Related research

Approaches in defence procurement

The nature of contract procurement within the defence industry has witnessed a change from the traditional contracts (where contractors developed and delivered systems and equipment to meet customer requirement) and spares inclusive contracts (where the contractor is required to provide spares and repairs for equipment) to an approach which contracts for availability and capability.

In availability contracting, the contractor is required to deliver whole platforms and equipment to meet agreed performance and standards of output which could be presented as key performance indicators, while capability contracting requires the contractor to deliver a capability to achieve the required performance standards. This is illustrated in Fig. 1 (MoD 2005; Cushway 2006). The customer's desire for equipment reliability in order to reduce the movement of spares and repairs meant that the focus was to pay for

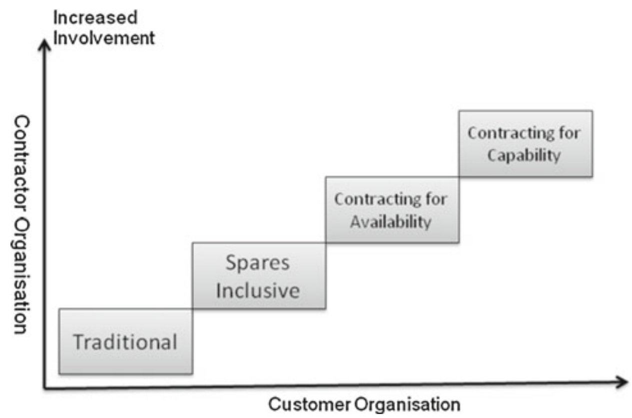

Fig. 1 The evolution of defence contracts adapted from MoD (2005)

availability of equipment, not repairs. Previous methods of contracting for delivery and repairs separately did not incentivise the contractor to deliver equipment for reliability. Availability contracting allows the customer to pay for the use of the equipment and contractors to generate returns continuously over a longer period while providing greater equipment availability (MoD 2005). This type of contracting is more common within the defence industry as seen in the Integrated Merlin Operational Support (IMOS) contract, Availability Transformation Tornado Aircraft Contract (ATTAC) fleet, Harrier Platform Availability Contract (HPAC) and the UK's Eurofighter Typhoon fleet.

Capability contracting is concerned with the provision of a capability rather than the availability of a platform. It is the destination that the industry is heading for; hence few examples of this form of contracting exist such as e.g. air-to-air refuelling and Skynet 5 communications contract (MoD 2005).

Another initiative introduced by the MoD is Partnering. Partnering is a procurement approach that uses "partnering specific terms and conditions" to facilitate the successful delivery of joint objectives between the customer and the solution provider (MoD 2008). The approach creates legal obligations and contractual commitments which is strengthened by a structured and rigorous approach to relationship management. The contracting approach provides an incentive for collaboration between the partners and a better chance of delivering the capability required within acceptable performance, time and cost parameters. Whilst the initiative encourages closer collaboration between the customer and the solution provider or manufacturer, it is not a replacement for competition; hence the Competition Act 1988 is still applied in this type of contract. There is need for thorough consideration before partnering as it is only suitable if the project team is able to ascertain that the investment required to partner would benefit the project, normally with a value over £5 million (MoD 2008).

The level of information the customer releases to the solution provider is determined by the procurement strategy employed whether single or competitive bid. In a competitive bid, the customer normally provides an indicative funding allocation to contractors without extra financial information. Nevertheless, a spend profile could be provided when there are doubts about the affordability of the project. In a single bid situation, the customer provides data based on the willingness of both parties to share data and the knowledge of the supplier's offer.

In adopting any of the various procurement approaches presented above, different types of contracts can be implemented. This means, for example in an availability contract, different types of contracts can be implemented. Roy and Cheruvu (2009) reviewed types of defence contracts and grouped them into the following categories namely; fixed-price contracts, incentive contracts, indefinite-delivery contracts and cost-reimbursement contracts. The choice of a particular type of contract is affected factors including price competition, price analysis, cost analysis, nature of the requirement, urgency of the requirement, period of performance, contractor's technical capability and financial responsibility, extent and nature of proposed subcontracting and acquisition history.

Approaches in life cycle costing

LCC was initially applied by the US Department of Defense based on the notion that operation and support costs for typical weapon systems accounted for as much as 75% of the total cost (Gupta 1983) which is committed at the design stage. In order to manage the cost of products, methodologies such as *design-for-cost* and *design-to-cost* were developed. Design-for-cost involves using engineering process technology to reduce life cycle cost while design-to-cost involves developing a design that complies with the functional requirements for a given cost target (Dean and Unal 1992; Asiedu and Gu 1998). Design-to-cost is a similar concept to *target costing* which involves profit planning and cost management to design product cost at the research and development or concept stage rather than reduce cost at the manufacturing stage (Atkinson et al. 2001). Despite the success of the methods stated above, this is a view that designers still need methodologies that directly provide cost information to them.

Chytka et al. (2006) explained that Life Cycle Cost Analysis (LCCA) is a systematic approach of applying economics in deciding the best solution for a design over the useful life of an equipment while affordability analysis employs the outputs of a LCCA to apply investment strategies over the life cycle of an equipment like reserve strategies, etc. This shows the relationship between LCC and affordability.

Another technique applied in industry is *Earned Value Management (EVM)* which is 'an integrated management control system for assessing, understanding and quantifying what a contractor or field activity is achieving with program dollars' (National Aeronautics and Space Administration, 2010). It relates resource planning and usage to schedules and technical performance requirement (Kim et al. 2003) by assessing the performance of the project given the resources consumed. Unlike the other costing approaches, EVM is carried out during the life cycle rather than the concept stage of the project to compare the performance of the project against the estimate and assess the value earned in the process, thereby providing project managers with a more accurate status of a project and areas for improvement.

Cost estimating models used in industry are mainly in three categories namely: parametric models, analogous models (estimating by analogy) and detailed models.

Parametric estimating is described as the generation and application of equations which describes relationships between cost schedules and measurable attributes of a system or equipment that must be created, sustained and retired (Dean 1995). Parametric costing could be applied in predicting the total LCC of a product/PSS or costs at different stages by employing regression analysis based on historical cost and technical information.

Analogous models are applied by identifying a similar product or component and adjusting its costs to find the differences between it and the target product (Shields and Young 1991). In order to benefit from this type of cost modeling, the products must share certain characteristics or components and the cost estimator must be able to accurately estimate the differences between the two products or equipment.

Detailed modeling is carried out in bottom-up estimating by estimating labour time and rates and material quantities and prices to estimate the direct costs of a product or activity (Shields and Young 1991). Indirect and overhead costs are apportioned using an allocation rate. This type of modeling is the most time consuming and it requires detailed knowledge of the product and processes. It could also be the most accurate approach. Other applications of LCC in accounting literature are target costing, kaizen costing, cost-plus, activity based costing and environmental costing.

Given the nature of defence contracts where the customer faces budget constraints and the manufacturer or contractor profit level is usually set. Design-for-cost, design-to-cost, target costing and cost-plus methods are usually applicable with the EVM technique. Similarly, other costing approaches could also be applied where applicable. However, it is important to note that wrong estimates would lead to higher actual costs which could double the estimate. This would have a negative effect on the affordability of a product or PSS. Furthermore, overestimation of cost could be detrimental leading to loss of contract, given the budget of the customer. After the estimate is done, an affordability assessment is done to determine whether the contract can be awarded based on the cost estimate from the LCC process and the customer budget A full description of the affordability process is described by Bankole et al. (2009b).

Affordability assessment

Customer affordability is a concept that is well established within the construction sector where housing providers try to assess whether housing can be afforded by certain groups of households. It is defined as ability to secure a 'given standard of housing (or different standards) at a price or rent which does not impose, in the eyes of some third party (usually the government) an unreasonable burden on household incomes' (Hancock 1993). It calculates the total cost of housing by adding the cost of renting the house with the cost of transport to and from the house as a fraction of the income to generate an index (The Centre for Transit-Oriented Development and Centre for Neighbourhood Technology 2007). Within the software sector, it is described as the ability to bear the cost of something (Bever and Collofello 2002) and the provision of services which can be afforded by customers at different income levels within the utility sector (Milne 2000). Within the aerospace sector, it is the 'degree to which the Whole Life Cycle Cost (WLCC) of an individual project or program is in consonance with the long range investment capability and evolving customer requirement' (Ray et al. 2006). The definition by Ray et al. (2006) was developed by the Network of Excellence in Affordability Engineering (NoE in AE) at Cranfield University which is adopted for both defence and aerospace sectors. It highlights the need for a correlation between the WLCC of defence projects and the financial ability of the customer not just to support the defence project at manufacturing stage, but throughout the life cycle which could be up to 40 years or more. The quantitative measures currently employed in assessing customer affordability within the defence industry are the WLCC and Customer Budget which is represented as Customer Available to Spend (CATS). This paper proposes an affordability system which takes account of both qualitative and quantitative factors in order to assess customer affordability and provide recommendations for improving customer affordability. This is fully explained in Section "Development of customer affordability assessment system". Section "Methodology" below describes the approach in the development the system and the framework.

Methodology

Research methodology

The methodology adopted within this study combines a literature review approach, a case study approach and industrial interaction which is represented in the Fig. 2. The process began with the identification of the research themes which are related to customer affordability and defence contracts. Keywords such as affordability, customer affordability, defence contracts, customer affordability assessment and availability contracts were identified and these formed the basis of the literature review which later led to the development of the interview protocol for industrial interaction. Affordability was used as a keyword because most literature use the word *affordability*, and not *customer affordability*, however this paper focuses on *customer affordability*. The difference between both terms is explained later on in this section. In conducting the literature review about the subject, two approaches were adopted namely: Delphi methods and Content analysis (Li and Cavusgil 1995; Marasco 2008). The Delphi method could be applied in two approaches such as *Delphi exercise* and *Delphi conference* (Turoff and Linstone 2002).

The *Delphi exercise* approach was employed by the authors of this paper and the questionnaires were administered to 17 industrial experts within the defence sectors in semi-structured interview sessions which lasted for over 30 h. The job roles of the interviewees (both from customer and manufacturer firms) were concerned with cost estimation, contracting, appraising and evaluating contracts against long term budgets. Some of the questions employed in conducting the interviews are listed below.

- What is your understanding of affordability?
- What are the different approaches to defence contracting?
- What are the factors that affect defence contracts?
- What additional risks come in terms affordability when contracting for availability contracts?

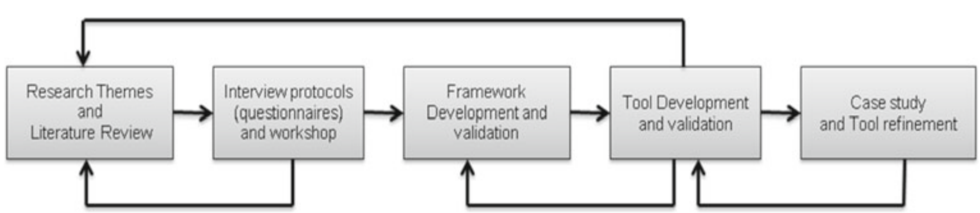

Fig. 2 Research methodology

The results were recorded both manually on paper and stored electronically at the earlier phases of the research. During the data collection, data was usually stored electronically and the analysis and results formed the input for the customer affordability framework.

Content analysis involves the search and selection of articles as well as classification of the collected articles based on their content. This approach was adapted to a limited degree in this study as the study does not present literature materials based on classification; rather it presents findings from the literature within the paper. The detailed account of the classification and categorisation of the literature reviewed is presented in Bankole et al. (2010). A search was carried out on the Compendex, Inspec, Scopus and Emerald databases as well as the Google engine and relevant materials were collected for the review. Both published and unpublished literature was involved in the review and findings from literature were employed in developing the questionnaires for the industrial interaction.

Framework methodology

The interview protocol involved the selection of the companies to be involved within the study which were three main companies (two manufacturers and one customer). The companies were selected based on their industries (aerospace and defence) and their willingness to participate in the study. Familiarisation interviews would be held with the companies for the researchers to gain fundamental understanding of their operations and help the industrial experts understand the context of the study in order to commence initial data collection and to identify potential case studies for the study. The initial interview sessions were held with industrial experts across the selected organisations. Interviews sessions would range from 60 to 150 minutes and responses were captured through audio recording and hand-written notes. Interview results were analysed using the MindManager software which helped to produce Mind maps based on various themes identified. These results enabled the researchers understand the current practice of defence contracting, manufacturing and through life cost estimation and the qualitative and quantitative factors in customer affordability assessment. The analysis led to further literature review of recommended materials and other useful materials. The authors had initial discussions and held a workshop about the current findings and the architecture of the proposed framework, input for the system and the suitable software for the affordability prototype system development. A schematic was designed to be built using the Microsoft Excel software as recommended by the industrial partners due to its functionality and accessibility of industrial experts and the researchers. The framework was validated with the industrial partners. The results from the initial interview sessions as well as the literature review provided data for the customer affordability system development. Three affordability perspectives were been identified (customer affordability, supplier sustainability and manufacturer profitability) and further industrial interactions were conducted to focus on each perspective the affordability model. In addition to the three perspectives, there was the need to determine the level of information availability in order to perform the assessment for the three perspectives. The system designed to assess information availability was fully described in Bankole et al. (2009a), however, this paper focuses on the *customer affordability system* which predicts the customer's ability to afford a defence project. The next stage of the methodology was the validation of the affordability system (described in Section "System validation"), and a real-life case study was applied to the affordability system. The customer affordability framework is presented in (Fig. 3).

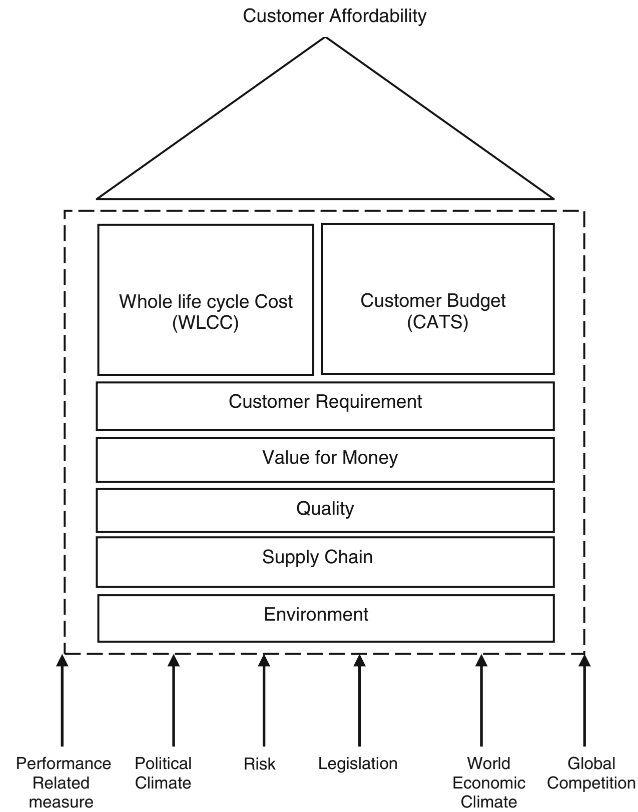

Fig. 3 Customer affordability framework

All qualitative and quantitative customer affordability factors from indentified within the defence sector are further grouped into pillars, drivers and capabilities within the customer affordability Framework (Fig. 3). The pillars are the two quantitative factors, WLCC and CATS, which are the most important factors. The capabilities (major qualitative factors) required in assuring customer affordability include customer requirement, Value For Money (VFM), quality, supply chain and environment. The drivers are those qualitative factors which are outside the control of the manufacturer, yet they drive customer affordability. These include risk, performance related measures, political climate, legislation, world economic climate and global competition. These pillars, drivers, and capabilities are explained fully in Section "Development of customer affordability assessment system". The output of the framework is customer affordability that is sustainable over the lifecycle of the defence project. Having followed this methodology, the content and scope of the system is described in section "Development of customer affordability assessment system".

Development of customer affordability assessment system

The findings on the subject of affordability from literature and industrial interaction formed the input for the customer affordability system.

The literature review also examined perspectives and factors influencing the affordability of business and individual customers across different industries. However, the findings presented in this paper are focussed on the defence sector which is in the business customer category. These factors were employed in developing measurement techniques for customer affordability such as the Affordability Index (AI) for the defence and aerospace industries. The authors identified the highest number of customer affordability factors within the aerospace and defence industries which are explained in Table 1. During the interaction with experts within the aerospace and defence industries, it was emerged that affordability was a concern for the three main partners within a defence contract who are the customer, manufacturer (prime contractor) and the low-tier supplier(s). The customer is keen to see that its requirement would be delivered within the budget allocation available, the prime contractor is concerned about the delivery of the customer requirement and maintaining the desired level of profitability and equally concerned about having suppliers that would be financially sustainable over the lifecycle of the contract. However, this paper is focuses on one of the perspectives of affordability which is the *customer affordability*.

The customer affordability assessment system has three main benefits namely:

- Enable the customer to evaluate a bid proposal submitted by industry to assess whether the solution would be affordable over the project life based on the qualitative and quantitative factors. It could also highlight potential risk involved in the proposed solution.
- It enables the manufacturer understand the customer's view of affordability and consider how to make the project more affordable as well as how to increase the Customer's Willingness To Pay (CWTP).
- It provides recommendations in order to improve affordability based on each affordability factor.

Customer affordability factors

A total of fourteen customer affordability factors were identified in literature from the aerospace and defence industries and presented in Table 2 (Bankole et al. 2010). These factors represent the view of customer and the manufacturer. The first two factors are the major factors affecting customer affordability and they are quantitative in nature while the remaining twelve factors are qualitative in nature. In order to assess customer affordability, both qualitative and quantitative factors needed to be taken into account, nevertheless, some of the qualitative are outside the control of the manufacturers (world economic climate, other, legislation, global competition and political climate). These factors which cannot be influenced by the manufacturer are not included in the customer affordability assessment in order to perform a better assessment. Within the customer affordability system, the respondent is required to provide actual values for the two quantitative factors which are CATS and WLCC as input for the AI. The AI is a mathematical equation used to generate a score which is an indication of how affordable a project is. The AI for the defence sector was originally generated by Nogal (2006) and it has been revised by Bankole et al. (2010) to improve accuracy with conditions under which the AI would generate a suitable score. Nogal (2006) identified two quantitative factors and ten qualitative factors within civil aerospace domain which formed the basis of an AI which combined both qualitative and quantitative elements. However, Bankole et al. (2010) identified two quantitative factors same as (Nogal 2006) and twelve qualitative factors from the defence and aerospace sectors, some of which were similar to Nogal (2006)'s since both authors are considering the aerospace sector. The initial AI was not accurate because it combined variables which had different characteristics into one equation, therefore, (Bankole et al. 2010) retained the quantitative variables within the AI and suggested that a suitable method for assessing the qualitative factors which reflects the the importance and impact of each variable in a defence project. Also when the existing AI from the civil aerospace sector (Nogal 2006) was applied to case studies within the defence sector, it generated some results which were inaccurate, hence the need to provide conditions under which the quantitative part of the AI should be applied in the defence sector. The new AI is presented below with conditions.

$$\mathrm{AI} = \frac{\mathrm{CATS}}{\mathrm{WLCC}} * \left(1 - \left(\sum_{\mathrm{I}=1}^{\mathrm{n}} \frac{(\mathrm{C_I} - \mathrm{S_i})}{\mathrm{S_i}}\right) * \frac{1}{\mathrm{n}}\right) \quad \text{(i)}$$

Table 1 Affordability factors adapted from Bankole et al. (2009b)

Affordability factors	Description
Customer budget (CATS)	This refers the financial ability of the customer to procure a contract based on the budget allocation. It is also represented as Customer Available To Spend (CATS)
Whole life cycle cost (WLCC)	This refers to the cost of a contract across the life cycle from the concept stage to disposal
Requirement (R)	Customer requirement forms the basis of the contract and a change of requirement could increase the whole life cost of the project where extra effort is required in redesigning the system especially with be-spoke systems and services
Value for money (VFM)	The customer assesses tender responses for a PSS provision from supplier firm's against VFM. This could be done by employing three techniques namely: economy, efficiency, effectiveness
Environment (E)	This refers to the responsibility of firm towards the environment to ensure that their operations and activities are environmentally friendly to ensure sustainability
Supply chain (SC)	Lower tier suppliers are crucial to the delivery of both products and services for the duration of the availability or capability contract life. The challenge is to ensure continuity in the supply chain over the contract life
Quality (Q)	Customer focuses on a specific project and the financial commitment involved in that project to ascertain that the solution is delivered at high quality. Therefore, customer's affordability is influenced by perception and interpretation of quality
Legislation	Changes in UK, EU and International law, regulations, and protocols concerning environmental, safety, social issues can affect affordability. These impacts both the WLC at the outset of the project and the affordability of extant projects
Risk	This is defined as the combination of the probability of any event occurring and its consequences (positive or negative) on the contract. This should be assessed and adequate provision should be made while contracting in order to ensure the affordability of the contract. Risks could also be turned into opportunities
World economic climate	The economic climate is influenced by the inflation, interest rate and share prices. Exchange rate fluctuation between two currencies dictates how much one currency is worth in terms of the other. This could have a negative or positive effect on affordability
Global competition	The rules of competition drive the cost down. If competitors are offering lower prices, the supplier could be forced to reduce the cost of the service
	Suppliers/contractors from other countries could provide attractive offers in order to expand their customer base
Performance-related measure	In some contracts, full payment is made upon contract delivery; hence the level of customer satisfaction with the delivery and performance of capability could impact the customer's willingness to pay based on system or equipment performance. This is linked directly to performance management
Political climate	The defence industry's operations are typically affected by the nation's political climate. Perceived threats from other nations, could affect the government's willingness to invest in defence projects
Other	This applies to any other factors which arise depending on the nature of the project

where, CATS = Total customer budget; WLCC = Whole life cycle cost; i = the years where cost exceeds the expected spending ability of the customer in that year; Ci = Cost incurred in the ith year; Si = Expected spending ability (budget) of the customer for the ith year; n = total number of years the cost has exceeded the spending

The conditions to apply this Index are:

(i) Total customer budget (CATS) > 0
(ii) Where individual year's spend is 0, replace with 1
(iii) If Sum of WLCC $<$ CATS or WLCC = CATS, then only apply CATS/WLCC.

Table 2 Explanation of factor scores

Colour	Capability level	Average	Level of risk
Score			
	High	<12	Low risk
	Medium	≥12, <16	Medium risk
	Low	≥ 16	High risk
Weight			
	High	<12	Low risk
	Medium	≥12, <16	Medium risk
	Low	≥16	High risk

(iv) If there are any violations (individual year's cost > spend) during the project life cycle, then apply full AI.

The result of the index is an indication of how affordable a project is.

If the Score >1, the project is more affordable; if Score =1, project is just affordable and if Score <1, the project is unaffordable.

The major customer affordability factors that were included within the affordability system have been presented in bold in Table 2.

The authors have also provided guidelines for the major qualitative factors in order to allocate weights and scores for each factor within the affordability system. The weights give an indication of the importance while the scores provide an assessment of the qualitative factor. In each qualitative factor, risk is an element which is common; therefore, risk is shared among all the other factors so it is not considered separately. Also performance-related measure could be an approach adapted to measure value for money; hence guidelines were developed for five factors which are within the control of the defence partners.

(i) **Requirement**: This requirement which is based on customer need is dynamic in nature. A contract which could last for 15 years or more would certainly change over time. There is a need to manage the impact of this change on WLC of the project as well as schedule in order to ensure the delivery of an affordable solution to the customer which secures manufacturer profitability. Measures of assessing customer affordability based on requirement are presented in Table 3:

(a) *Customer Requirement*: To what level does the proposed solution fulfil customer requirement?
(b) *Integration of systems and equipment*: To what level is the proposed solution able to achieve interoperability between different systems and equipment?
(c) *Liability allocation*: What is the level of clarity in the definition of responsibility (for the activities and operations) within the project?
(d) *Schedule*: What is the level of planning in the schedule (resources) to ensure the contract requirement can be delivered to satisfy customer requirement?
(e) *Performance and cost targets*: What is the likelihood that the project requirement would be delivered within the budget, and according to contract requirement?
(f) *Flexibility*: What is the degree of flexibility within the solution to adapt to change in requirement?
(g) *Technology Readiness Level (TRL)*: What is the scale of technology maturity within the proposed solution? (See Acquisition Operating Framework 2008 for definitions of TRL Scales).

(ii) **Environment**: This refers to the responsibility of the company towards the environment to ensure that activities and operations are environmentally friendly. There is a need for an on-going plan for environmental sustainability which must include; production and consumption processes, climate change and energy, natural resource protection and environmental enhancement. The scores are represented in Table 4.

(a) *Plan for disposal*: What is the level of long-term planning for the end of the life of the equipment?
(b) *Environmental Impact*: What is the level of effort that have gone into developing initiatives or schemes to ensure environmentally friendly processes e.g. emissions reduction, energy reduction, water reduction, green supply chain, green information technology and green data centres?
(c) *Change in Legislation*: How responsive is the contractor to new legislation and regulations?

(iii) **Value For Money (VFM)**: VFM has been described as a judgement of the "quality of provision, processes or outcomes against the monetary cost of making the provision, undertaking the process or achieving the outcomes" (Harvey 2009). The customer assesses tender responses from supplier firms against VFM. This could be done by employing the measures described below with the score allocation in Table 5.

(a) *Efficiency*: To what degree will the proposed solution maximise resource usage throughout the contract duration?

Table 3 Requirement factor scores

Score	Definition
Customer requirement	
1	>95% fulfilment
3	>85% fulfilment
5	$\leq$70% fulfilment
Integration of systems and equipment	
1	Interoperability is achieved without any issues relating to integration and interoperability at high level
3	Interoperability is achieved but there are some issues relating to integration
5	There are serious issues with interoperability
Liability allocation	
1	All responsibility is fully allocated and accepted
3	Some responsibility have been allocated
5	No responsibility have been allocated
Schedule	
1	Critical plan is known and scheduled with risk and uncertainty
3	Scheduled is planned
5	Scheduled is not planned
Performance and cost targets	
Cost	
1	Fulfil customer requirement under budget allocation
3	Fulfil customer requirement within budget allocation
5	Fulfil customer requirement over budget allocation
Performance	
1	Fulfil all customer requirement
3	Fulfil some customer requirement
5	Fulfil little or no customer requirement
Flexibility	
1	Flexibility within solution at reasonable cost
3	Flexibility within solution with extra cost
5	No flexibility within solution
Technology readiness level (TRL)	
1	TRL Scales 7, 8 and 9
3	TRL Scales 4, 5 and 6
5	TRL Scales 1, 2 and 3

(b) *Effectiveness*: To what degree will the solution fulfil customer requirement effectively throughout the contract duration? (Capability and competence)

(c) *Economy*: To what degree will the proposed solution be delivered with savings in cost, time or effort throughout the contract duration? (Erlendsson 2002)

(d) *Performance-Related measure*: To what degree would the proposed solution satisfy the key performance indicators for the contract?

(e) *Availability*: What is degree of availability the proposed solution is able to sustain overtime?

(f) *Technology innovation*: What level of technological development is the supplier firm able to provide in the proposed solution?

(iv) **Supply chain**: Every contract requires the activities of lower tier suppliers in order to deliver a fully integrated solution to the customer over the life of the availability or capability contract. Due to the lengthy duration of the contracts, manufacturers face the

Table 4 Environment factor scores

Score	Definition
Plan for disposal	
1	Supplier has long-term plan for disposal
3	Supplier has short-term plan for disposal
5	Supplier has no plan for disposal
Environmental impact	
1	High level of planning for environmentally friendly initiatives
3	Medium level of planning for environmentally friendly initiatives
5	Low level of planning for environmentally friendly initiatives
Change in legislation	
1	Contractor is very quick to comply with new legislation
3	Contractor gradually complies with new legislation
5	Contractor is very slow to comply with new legislation

Table 5 VFM factor scores

Score	Definition
Efficiency	
1	Fulfil customer requirement with reduced resource usage
3	Fulfil customer requirement without reduced resource usage
5	Fulfil customer requirement with increased resource usage
Effectiveness	
1	Fulfil customer requirement with maximum capability and competence
3	Fulfil customer requirement with minimum capability and competence
5	Lacks capability and competence to fulfil customer requirement
Economy	
1	Fulfil customer requirement with savings in cost, time & effort
3	Fulfil customer requirement without savings in cost or time or effort
5	Unable to fulfil customer requirement
Performance-related measure	
1	>95% satisfaction
3	>90% satisfaction
5	<80% satisfaction
Availability	
1	High level of availability sustainment
3	Medium level of availability sustainment
5	Low level of availability sustainment
Technology innovation	
1	Actual technology system qualified through successful mission operations
3	Technology system/subsystem model or prototype demonstration in a relevant environment
5	Analytical and experimental critical function and/or characteristic proof-of-concept

challenge of ensuring continuity in the supply chain. This could be assessed by the following measures with the scores in Table 6.

(a) *Type of contractor*: Is the contract to be awarded to a prime contractor or individual suppliers? The benefit is that day-to-day management of the contract would become the responsibility of the prime contractor not the customer if the contract is awarded to a prime contractor.

(b) *Supplier certification status*: To what level are the certification status and the maturity of the contractor's quality management system satisfactory?

Table 6 Supply chain factor scores

Type of contractor	
Type	*Select one*
Prime contractor	
Individual suppliers	
Supplier certification status	
Score	*Definition*
1	Fully approved supplier
3	Non-approved, but has international accreditation e.g. AS9100, ISO 9001
5	Non-approved supplier
Contractor relationship	
Relationship	*Please select one*
Long term	
Short term	
Scope of supply chain	
Contractor	*Percentage (Please provide)*
Domestic	
Foreign	
Scope of supply chain	
Foreign contractor	*Please select one*
Established trading partner	
New trading partner	
Financial capability	
Contractor capability	*Please select one*
High	
Low	
Price	
Score	*Definition*
1	Competitive price with extra value e.g. economies of scale
3	Competitive price without extra value
5	High price without value
Number of unique interface	
Unique interfaces	*Number (Please provide)*
Number of nations	
Nations	*Number (Please provide)*
Nature of nations' working relationship	
Score	*Definition*
1	Excellent working relationship based on historical relationship
3	Good working relationship based on historical relationship
5	No previous working relationship
Number of vendors	
Vendors	*Number (Please provide)*
Length of vendor working relationship	
Score	*Definition*
1	High relative to industry average
3	Medium relative to industry average
5	Low relative to industry average

Table 7 Quality factor scores

Innovation	
Score	*Definition*
5	Highly innovative with high value
3	Highly innovative with low value
1	Non-innovative solution
Regulations and standards	
Solution meet quality regulations	*Please select one*
Yes	
No	
Requirement delivery	
Score	*Definition*
5	Achieving customer satisfaction the first time
3	Achieving customer satisfaction after iteration
1	Failure to achieve satisfaction

(c) *Contractor relationship*: Does the customer have a long or short-term relationship with the contractor? (A short-term relationship may not result in higher level of risk, but no relationship at all could mean the level of risk is higher).

(d) *Scope of the supply chain*: What percentage of major contractors are domestic or foreign? (Foreign suppliers may not pose a higher level of risk in some cases, but if there are more foreign contractors compared to the domestic ones, this might pose a higher level of risk to the contract delivery. This is why it is also important to know if the foreign company is an established trading partner. The presence of foreign contractor means there is need for smooth collaboration within the supply chain partners to deliver an affordable solution to the customer).

(e) *Financial capability*: To what level is the contractor's financial capability satisfactory?

(f) *Price*: To what level is the contractor's price satisfactory?

(g) *Number of Nations*: How many nations are involved in the supply chain? This gives an indication about the length of the supply chain. The presence of foreign suppliers could affect lead time, cost (due to exchange rates) and other aspects of the project.
  – What is the nature of working relationship between the nations?

(h) *Number of Vendors*: How many vendors are involved in the supply chain?
  – How long have the vendors been working together?

(i) *Number of Unique Interfaces*: How many unique interfaces are involved in the project delivery?

(v) **Quality**: This has been described as the 'totality of features and characteristics of a product or service that bear on its ability to satisfy stated or implied need'. It could also include 'degree of excellence' and fitness for use (ISO8402) (Harvey and Green 1993). The assessment of quality varies depending on the customer's perception. It could be assessed in the following measure with the scores in Table 7.

(a) *Innovation*: What is the degree of innovation in the proposed solution?

(b) *Regulations and Standards*: Does the proposed solution satisfy the relevant UK/European or International regulations and agreements on quality (e.g. AS9100- Supply Chain 21 standards or ISO9100)?

(c) *Requirement delivery*: At what level of satisfaction would the proposed solution deliver the customer requirement (fitness for purpose and getting it right the first time)?

Uncertainty in customer affordability assessment

The nature of defence contracts means that uncertainties and risks are inherent in the contracts due to the long-duration and the complexity of the customer requirement. This means that the WLCC estimation and customer affordability assessment performed at the bidding stage would not be the same as actual cost and spend profile throughout the life cycle of the project. For this reason, uncertainty was imposed on the major quantitative factors affecting affordability namely

Table 8 Uncertainty ranges

	Uncertainty ranges	Years based on information audit
High	−20/+30%	7–10
Medium	−15/+20	4–6
Low	−10/+10%	1–3

WLCC, Customer budget. Uncertainty was not imposed on qualitative weighted scores as this would yield unrealistic results.Uncertainty is a term which is interpreted differently by different researchers and industrial experts. In cost estimation, uncertainty consideration is part of sensitivity analysis done after the cost estimate has been prepared. It is usually done together with risk assessment to develop minimum, most likely and maximum ranges for each risk element to identify the confidence level of the point estimate (GAO 2009). It could be easily mixed up with risk. Within this paper, the authors consider uncertainty is the difference between actual and predicted cost or budget estimate while risk as a major type of uncertainty. Uncertainty represents variability which could be positive or negative while risk is a type of uncertainty which has a negative impact on cost or budget.

Two approaches were adopted in representing uncertainty.

- The Association for the Advancement of Cost Engineering (AACE) uncertainty ranges – The AACE Cost Estimate Classification System provides guidelines for applying the general principles of estimate classification to asset project cost estimates. The cost estimates were categorised into 5 classes of estimates for which uncertainty ranges were defined. The authors refined these uncertainty ranges and derived three levels of uncertainty ranges for application within the affordability system. The refined uncertainty ranges are presented in Table 8. This means for the first three years of a 10 years contract, it is assumed that uncertainty would be low, in the next three years, (4–6), uncertainty would be medium and in the last 4 years (7–10), uncertainty would be high. The ranges would be applied based on the levels.
- The Affordability Information Capability Audit—An Audit is performed to assess the level of information available about the project for each stage of the life cycle (Bankole et al. 2009a). This audit gives an indication of periods within the life cycle where information availability is higher and when it is lower. This helps to identify periods where uncertainty is higher and when uncertainty is lower.

This combined approach means that the uncertainty ranges derived from the AACE classification system is applied to the WLCC, CATS figures while the affordability information capability audit result gives an indication of when to apply the higher uncertainty ranges and when to apply the lower ranges. These ranges were applied using the Crystal Ball software by Oracle which uses a monte-carlo simulation (Fig. 4) to generate different possible outcomes with a uniform distribution to provide the minimum, most likely and maximum values for each input.

System scenario

The customer affordability factors and components are the input for the customer affordability framework which is implemented as a software prototype system. The affordability system has three main activities namely, quantitative customer affordability assessment, qualitative customer affordability assessment and improvement actions selection. The results of these activities are stored in the database. The customer affordability architecture is presented in Fig. 5. For the quantitative assessment, the user is prompted to provide WLCC and CATS profiles in order to generate the AI. Also uncertainty ranges are applied to profiles to generate WLCC and CATS with uncertainty. In order to carry out the qualitative assessment the user is required to allocate scores for each qualitative affordability factor component. Scores (1, 3, 5) and weights (1–5) should be allocated for each component for each measure of the customer affordability factors components. The highest score is 1 while the lowest is 5. The highest weight is 5 while the lowest is 1. The scores give an indication of the capability of the proposed solution to be affordable in terms of the customer affordability factors while the weights indicate the importance of the factors in the proposed solution. The weights and scores are multiplied together to obtain weighted scores. The weighted scores are presented in a colour coded table like a traffic light system. The results and the interpretation of each result are presented in (Table 1). After the assessment, a set of improvement actions are provided for the user to select the actions that are most suitable for the project based on the affordability prediction result.

System validation

The customer affordability factors, measures and improvement actions were validated with experts from three defence

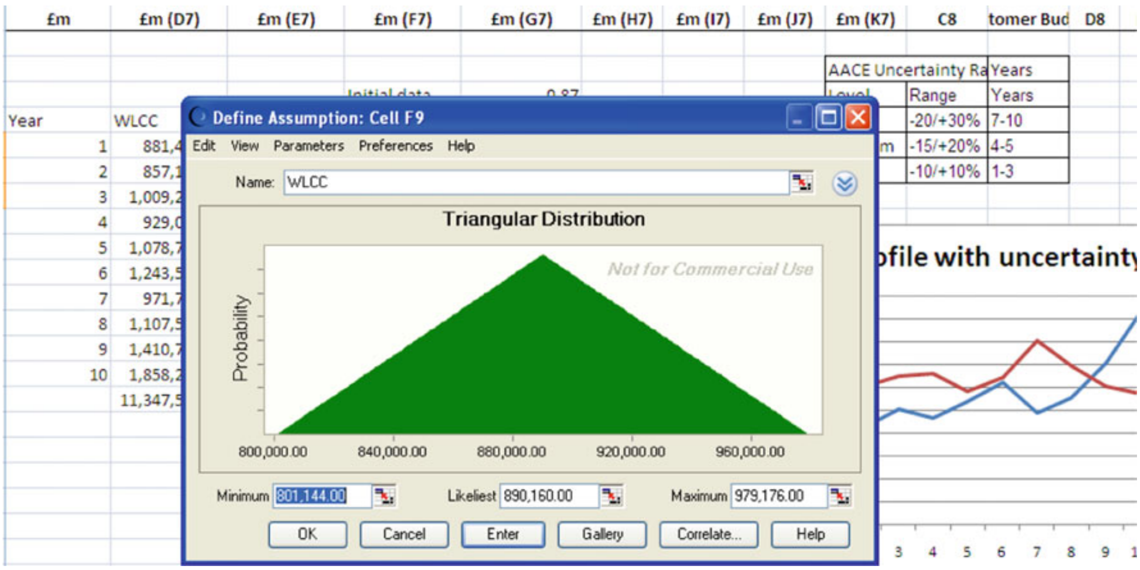

Fig. 4 Crystal ball simulation

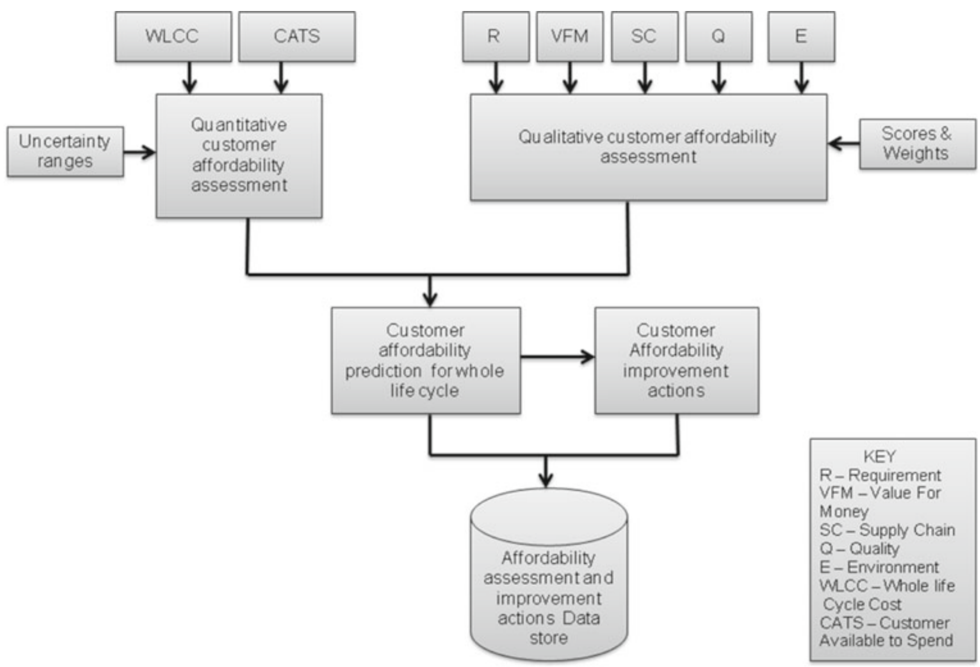

Fig. 5 Customer affordability system architecture

companies (contractor) through four semi-structured validation sessions. The first session was aimed at clarifying the customer affordability factors and selecting those factors to be included within the customer affordability system. The second session was focussed on validating the measures for assessing the customer affordability factor components. The third session was focussed on clarifying the improvement actions while the fourth session was aimed at validating the customer affordability system in terms of usability, appearance, logic and functionality. During these sessions, the researcher presented the context of customer affordability with the factors identified and validation questionnaires were administered where appropriate. The questionnaires were aimed at clarifying the various affordability factors, and the factor components with each individual scores and weights as well as the suggestions for improvement. On some occasions the researcher demonstrated the customer affordability system to the respondent in order to obtain feedback. Also a list of the improvement actions was provided for the experts to check the relevance and appropriateness of each action. The sessions helped to identify major (quantitative) and qualitative affordability factors to be included within the system since it were not feasible to include all the factors. It also helped to refine the individual scores for each of the factor components in addition to the improvement actions in order to make them more suitable to improve the affordability of defence projects. Upon completion of the validation sessions, the system was applied to a case study from real-life defence project.

Case study application

Due to the sensitivity of corporate data, some background information about the case study have been omitted or altered within this paper. This does not affect the results and the authenticity of the case study.

Description

The case study is based on a non-competitive firm price contract between a prime contractor and the UK (MoD). Initially the contract duration was planned to be 5 years, however due to affordability issues, it was decided to spread the cost over a longer period of time, hence the contract duration was extended to 10 years for a User Control Device-Next Generation (UCD-NG) communications system. The focus of the project is to deliver the User Control Device Next Generation (BUCD NG). The existing project had obsolescence issues inherent in it which would be inherited by the new project. The contract covers the Assessment, Demonstration, Manufacture and In-Service phases of the Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal (CADMID) cycle. The WLCC of the project was a just over £11 m. Currently the project was awarded on a single source basis; however, the customer wants to run a small competition to further assess VFM in the project. This contract was first awarded to a different prime contractor, but the project was running, hence the customer's decision to re-award the contract to the current prime contractor within this case study. However, the previous sub-contractors/suppliers were retained and moved to work with the current prime contractor.

Case study process

The case study session which was conducted at the prime contractor's site, lasted for 180 minutes with the project manager. The session started with the Cranfield researcher delivering a 20-minute presentation to briefly explain the aim of the session as well as the information required from the case study to populate the customer affordability system. Afterwards, the managers provided a brief introduction about the case study to help the researcher gain a basic understanding of the case study. Next the customer affordability system was populated. The assessment was made after the project had been contracted and begun.

Customer affordability assessment—quantitative

Table 9 shows that customer budget is higher than WLCC over the life cycle and in each individual year apart from years 9 and 10. This is reflected by the profile in Fig. 6 where CATS values are presented in a steady straight line above the WLCC curve between years 1 and 8, while WLCC values are presented in a curve which rises above CATS in years 9 and 10. The total CATS is higher than WLCC (difference is the prime contractor's profit margin) which means that the project is affordable overall, however, it is important to take account of the variations in years 9 and 10 so the full AI is applied as described in Section "Uncertainty in customer affordability assessment". The AI = 0.75 which is less than 1. This means alhtough the project is nearly affordable as 0.75 is nearer to 1, the project is unaffordable by 25%.

Customer affordability assessment-qualitative

Table 10; Fig. 7 show that the project is most affordable based on the environment (all cells are coloured green), just affordable based on requirement and supply chain (green and amber cells) but less affordable based on VFM and quality factors (red, amber and green cells). The weighted scores range from 1 to 25. The quality factor has the highest weighted score of 20 in year 6, followed by VFM with weighted score of 18 in year 3 during the life cycle (although quality also has weighted scores of 18 across the life cycle). This is the case because the project started with an understanding of the customer requirement which formed the basis for contracting and affordability assessment, hence year 1 weighted scores are the most affordable for all the factors. However, after the start of the project, customer requirement was enhanced causing significant changes. This is why the weighted score for requirement is lower end of the medium rather than high. This also explains the reason why VFM is the least affordable as the prime contractor could not deliver an efficient, effective and economic solution with such a dynamic requirement. Also the quality of the solution would vary in an ever changing environment and innovation would be difficult to achieve. The weighted scores for most of the factors reduced in year 10 with the assumption that the project would improve overtime and stabilise in the long term since the project is still on-going. Recommendations for improvement are provided to enhance the project affordability based on each of the affordability factor components.

Table 9 CATS and WLCC values

Year	1	2	3	4	5	6	7	8	9	10	Total
Currency value	£m	£m	£m	£m	£m	£m	£m	£m	£m	£m	£m
WLCC	890,160	890,160	1,000,000	1,000,000	1,114,000	1,114,000	1,118,000	1,120,000	1,500,000	1,600,000	11,346,320
CATS	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	1,200,000	12,000,000

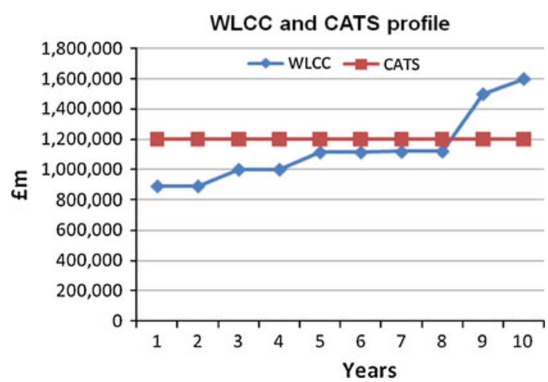

Fig. 6 CATS and WLCC profile

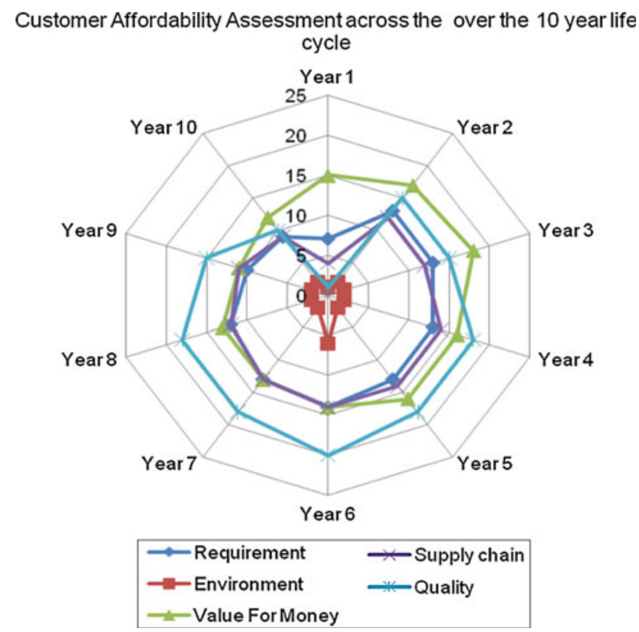

Fig. 7 Qualitative customer affordability results

The case study presented above reflects an initial prediction which may not reflect changes during the life of the project. In making an investment decision at the start of a project, an affordability prediction of 1.11 means the contract is affordable and profitable as the CATS would cover the WLCC and provide a margin for the manufacturer. The qualitative assessment result means that the project is more affordable in terms of conforming to environmental standards; just affordable as it would deliver the customer requirement with a reliable supply chain, but it may not offer VFM i.e. it may not achieve any cost or efficiency savings. Also the solution may not be innovative to achieve a high level of quality. These results are relative and it is important for the customer to identify which measures are most important under each affordability factor. Based on this, some re-negotiation could be done with the manufacturer to improve the affordability of the solution in terms of VFM and quality in a single bid. In a competitive bid, the customer could decide to invest in an alternative solution.

Uncertainty in affordability assessment

The uncertainty ranges were applied to the case study WLCC and CATS profiles as shown in Table 8 and the result is shown in Fig 8. Figure 4 shows that the CATS curve was straight line while the WLCC curve rises above the CATS curve in years 9 and 10. However, after applying the uncertainty ranges and running the crystal ball software, different results were

Table 10 Qualitative customer affordability weighted score

			Weighted scores								
Affordability factors	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Average
Requirement	7	13	13	13	13	14	13	12	10	9	12
Environment	1	2	2	2	2	6	2	2	2	2	2
Value for money	15	17	18	16	16	14	13	13	11	12	15
Supply chain	4	12	12	14	14	14	13	12	11	9	12
Quality	1	15	15	18	18	20	18	18	15	10	15

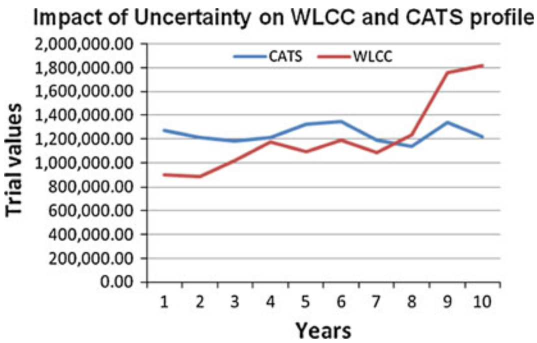

Fig. 8 CATS and WLCC profile with uncertainty

obtained and presented in Fig. 8. Figure 8 shows the WLCC curve rising above the CATS curve from years 8 to 10. The CATS curve is non-linear, with many variations. Total CATS is still higher than total WLCC, however the distribution is different as shown in Table 11 with an AI of 0.76. This shows that the AI with uncertainty increases slightly because the trial results for both CATS and WLCC figures were higher than the actual figures, especially total WLCC 7% increase.

Discussions and conclusions

The nature of defence contracts in terms of the complex customer requirement and long life cycle reveals the need for robust through life cost estimation and customer affordability assessment in order to procure and support the contracts. The paper identified fourteen qualitative and quantitative factors affecting customer affordability of defence contracts from literature and industry practice. Through industrial interaction seven major factors (two quantitative factors and five qualitative) were identified and included Also, measures were designed for the customer affordability factors in order to assign weights and scores for each factor which formed the main input for the affordability system. The qualitative factors identified through the research shows how the nature of the project and other factors surrounding the project could affect project affordability. The output of the affordability system provides an assessment of customer affordability based on scores weights and quantitative measures while providing suggested actions for improvement. The system was applied to a case study from the defence sector in this paper and the conclusion from the results are presented below:

Based on the project background, the initial duration of the contract was meant to be 5 years, but the customer negotiated with the solution provider to spread the cost over a longer period of time in order to secure additional funding for the project. This was done because the project was unaffordable initially.

Table 11 Uncertainty CATS and WLCC values

Year	1	2	3	4	5	6	7	8	9	10	Total
WLCC	898,930.19	883,840.58	1,019,238.44	1,175,556.47	1,095,898.36	1,189,981.57	1,085,436.49	1,234,662.35	1,754,640.34	1,819,858.94	12,158,043.73
CATS	1,272,659.99	1,214,331.10	1,182,896.78	1,215,287.13	1,326,027.80	1,343,524.18	1,191,923.21	1,135,939.09	1,342,064.74	1,222,743.31	12,447,397.33

When a project becomes unaffordable, the steps taken to make a project affordable include:

- Capability evaluation: the customer and contractor re-assess the capability requirement to see where they could make trade-offs and take out the luxury requirement while focusing on the basic capability the customer needs.
- Quantity: the customer could choose to reduce the number of equipment or systems in order to reduce the total cost of the project and accept a lower quantity.
- Time: the customer could choose to spread the delivery of the requirement over time in other to reduce immediate expenditure and possibly with the aim of securing more budget allocation along the life of the project.

In this case study, the time option was employed to improve affordability. However, during the life cycle of the project, the customer requirement was greatly enhanced leading to huge cost increase. This shows the impact of uncertainty in customer affordability of defence projects. Uncertainty could cause variations in the CATS and WLCC figures while risk is a major type of uncertainty which has a negative effect on the WLCC and CATS. Defence contractors are faced with the challenge of mitigating the impact of uncertainty including risk both from supplier and customer sides. While many commercial tools exist to assess the impact of risk on a project such as the crystal ball software, there is a need to enhance the capability to handle uncertainty better which can vary in different projects and find ways of turning risks to opportunities for the customer and suppliers in order to maintain a competitive position in the industry.

In summary, the feedback from industrial experts reveal the usefulness of the affordability system in helping defence customer and contractor to make the right decisions at the bidding stage while assessing the impact of qualitative factors in addition CATS and WLCC. It also provides recommendations for improving project affordability. The limitation of the research is its focus on the defence sector.

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