Information Technology Planning For Collaborative Product Development Through Fuzzy QFD

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***Abstract*—Collaborative Product Development (CPD) becomes a more complex process to manage by the rapid technological change. As a consequence of various system features introduced by research groups and commercial packages, CPD practitioners lose track of the available platforms, protocols, applications, system features, and tools supporting CPD processes. This study aims to provide a mapping between the technological requirements for CPD and system features of these various infrastructures. Fuzzy Quality Function Deployment (QFD) is employed for mapping between requirements and features. An industrial expert is consulted for evaluation of derived relationships and consequently system features are prioritized.**

Keywords: Collaborative Product Development; Fuzzy QFD; Technology requirements.

I. INTRODUCTION

Due to its technology-centric nature, Collaborative Product Development (CPD) is typically based on technological infrastructures, which require for information technologies (IT) to be essential conveyors of good CPD performance [1]. However, the management of requirements and implementation of necessary tools to respond to these requirements constitute a complex process as the technological diversity grows rapidly. Current tools become hard to track and thus, evaluations are performed with incomplete and biased information given that assessing all systems is not possible.

Previous studies do not propose a comprehensive review of CPD systems mainly because these systems including various applications, tools, and plug-ins are numerous; they can be easily outdated by new researches and are only known by a limited community. On the other hand, various systems are proposed by literature and commercial ventures in order to facilitate collaboration, integration, co-design, and co-development processes of CPD teams.

In this highly uncertain environment, with various different requirements and numerous technological solutions, a systematic methodology is essential to plan the technological infrastructure needed to start and maintain the CPD process. Determining requirements and accordingly prioritizing technological response compose an important phase in IT planning. Some projects may require only communication tools, while others are dependent on highly skilled web-based engineering applications. A comprehensive and detailed planning methodology utilizing Quality Function Deployment (QFD) is introduced to help CPD practitioners in their development and collaboration efforts.

QFD is a well established methodology in transforming customer needs into engineering characteristics and therefore its House of Quality (HoQ) diagram appears to be a suitable tool for mapping needs of CPD into existing tools and technologies. Additionally, mapping is performed under a fuzzy environment in order to translate linguistic evaluations of the expert into quantifiable performance measures. The aim of this study is to introduce a comprehensible methodology for IT planning, which can be employed by CPD practitioners before launching CPD projects.

The study is organized as follows: next section introduces the technology planning literature, which covers studies in a general context. Then the fuzzy QFD is described and the methodology backgrounds are established. The fourth section presents CPD technology overview, which includes commonly used standards and environments, technology requirements and system features in CPD infrastructure. Then the IT planning with fuzzy QFD is presented with an evaluation of an industrial expert. The study concludes with a few remarks.

II. TECHNOLOGY PLANNING BACKGROUND

Use of proper technology is the most preferred factor in maintaining competitive advantage [2]. Systematic planning of technological infrastructure is therefore important in improving CPD performance. Efficiency and effectiveness of CPD are enhanced by appropriate implementation of tools and technologies enabling CPD [3], which can be attained through accurate mapping of requirements into the system features.

A technology planning framework is proposed by Porter et al. [4], which includes technology forecasting, as well as environmental analysis and aims to design organizational actions. Value adding chain concept requires the implementation of technology within all aspects of the business. Martin [5] also starts with technology forecasting

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and applies scenario analysis to define technology allocations according to short term and long term needs. Rip and Camp [6] propose a four step methodology, which starts with market research then determine product features and technology options for these features and finally finishes with future consideration of technology resources.

Pretorius and Wet [7] define a framework based on the hierarchy of the enterprise, business processes and functions. Technological assessment can be mapped on the relationship between technology and processes on the three dimensional framework. Kumar and Midha [8] employ. They utilize the QFD approach to compare company's requirements in CPD with different functionalities of Product Data Management (PDM) systems and technical specifications are then compared to a specific PDM system.

Büyüközkan et al. [3] present a comprehensive review on tools, techniques and technologies enabling agile manufacturing in concurrent Product Development (PD). Rodriguez and Al-Ashaab [9] identify CPD supporting system characteristics and classify corresponding technological requirements. They also perform a survey in injection mould industry and they propose a knowledge based CPD system architecture responding to industrial requirements.

Koc and Mutu [2] present a technology planning methodology, from selection of competitive priorities to designing the activities, by integrating different system design perspectives through AD. Rueda and Kocaoglu [10] state that market and technology performance uncertainty make technological investment highly risky and they focus on diffusion of emerging technologies. They combine bibliometrics analysis, Delphi method, utility curves, and scenarios to define a composite indicator for the diffusion. Shengbin et al. [11] focus on technology roadmap concept and they present a visual guide to map market, product, and technologies to achieve technology selection. The three phased design process includes trend discussion, industrial and academic investigation, expert feedback on technological demand and it provides a tool to make strategic level technology selection decision.

Luh et al. [12] combine Design Structure Matrix with Fuzzy Sets Theory into FDSM to present a dynamic planning method for PD, increasing PD efficiency and decreasing development time. Ko [13] also employs FDSM to present a methodology enhancing PD management by organizing design activities and measuring dependency strength. Palacio et al. [14] presents a tool to facilitate collaboration in distributed Software Development (SD) teams, which aims to increase collaboration awareness by focusing on individuals and their activities.

Previous studies do not address a generic approach, which investigates and classifies the CPD requirements, as well as the tools and techniques provided by researchers and commercial packages. This study aims to introduce a planning framework within the fuzzy HoQ in order to capture these aspects and map their relationships.

III. FUZZY QFD OVERVIEW

HoQ, the planning tool within QFD methodology, can be described as a “conceptual map that provides the means of inter-functional planning and communications” [15]. It translates customer needs into customer attributes (CAs) in order to meet them through engineering characteristics (ECs).

As a first step in constructing a HoQ, CAs are collected from customers (Domain 1). Then engineering teams try to answer the question “how to achieve this attribute”. ECs that affect CAs are listed accordingly (Domain 2). CAs are prioritized in order to have a trade off basis in the case of conflicting objectives (Domain 3). As depicted in Fig. 1, right hand side of HoQ offers a benchmarking tool, where customer perception of other brands as well as focal firm’s brand in response to CAs is depicted (Domain 3a).

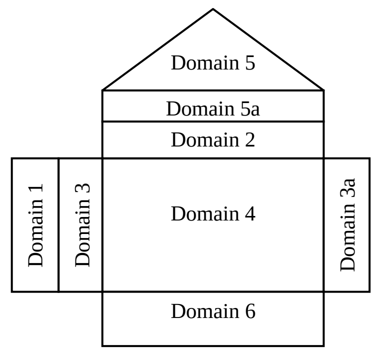

Figure 1 Main domains of HoQ

Then relationships between CAs and ECs are represented in symbols in accordance with the strength of the relationship (strong positive, medium negative, etc.). This step of the methodology serves to identify how an EC can affect a specific CA (Domain 4).

ECs effect on each other is represented in the roof matrix of the HoQ (Domain 5). Interdependent characteristics are thus displayed and the total outcome of engineering change is visualized. ECs are also marked regarding the direction of change in that specific characteristic (Domain 5a). Finally, target values and the degree of technical difficulty are set for ECs in order to present the amount of work and its complexity (Domain 6).

Majority of QFD applications stop at the planning stage, i.e. the HoQ and nevertheless, many benefits can be achieved through only the first matrix [16]. However, conventional HoQ matrix is not sufficient in describing the relationships between CAs and ECs. In some cases, application is performed in a fuzzy environment. Fuzzy QFD is employed in these cases in order to translate the vagueness of relationships and the subjectivity of the evaluator into quantifiable data.

Literature proposes many examples of fuzzy QFD applications. Şen and Baraçlı [16] investigate enterprise software selection requirements with fuzzy QFD. Linguistic variables are employed to prioritize non-functional criteria

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in order to provide a decision making framework to determine the order of criteria to be satisfied during software selection decisions of a company. In their two concurrent studies [17] and [18], Vinodh and Chintha investigate the enabling effect of fuzzy QFD to leanness and agility in a manufacturing organization. Fuzzy QFD is employed to prioritize the lean competitive bases, lean attributes, lean enablers in one case and the agile decision domains, agile attributes and agile enablers in the other by employing linguistic terms for both relationship matrix and correlations.

Lee and Lin [19] employ fuzzy QFD in PD. They incorporate fuzzy Delphi, fuzzy Interpretive Structure Modelling and fuzzy Analytic Network Process into QFD framework. Linguistic variables are employed for both relationships between CAs and ECs and the correlation between CAs to investigate priorities of PD in CAs, ECs, part characteristics, key process operations, and production requirements. Liu [20] employs fuzzy QFD to investigate priorities in product design and selection by (1) computing the relative importance of CAs, (2) computing the final importance of CAs and (3) computing the final importance of ECs through linguistic variables. Their methodology is also two phased, the second phase adopting a multi-criteria decision making approach. Jia and Bai [21] apply fuzzy QFD in manufacturing strategy development. Fuzzy integrated HoQ helps to capture the highly imprecise and vague nature of the strategy decisions.

In this study QFD is employed in a fuzzy environment considering that IT planning of CPD projects, in terms of requirements and features, is dependent on subjective judgments of CPD managers,. We aim to translate subjective and linguistic judgments of evaluators into quantifiable relationships by integrating fuzzy sets theory into HoQ. In the proposed methodology; CA weightings, CA-EC relationships, and EC correlations are defined in linguistic terms and then translated into triangular fuzzy numbers (TFNs) in the form of (l, m, u) .After defining CAs and ECs for the study, the industrial expert is consulted for his judgments. Collected linguistic judgments are fuzzified.

Fuzzy computation processes in this study are adapted from Vinodh and Chintha [18]. The relationship matrix and the weights of CAs are employed to compute the relative importance of ECs as follows:

$$RI_j = \sum_{i=1}^{n} W_i \otimes R_{ij},\ j = 1,\ldots,m. \quad (1)$$

Then the correlation matrix is considered. The final score of the j^{th} EC is computed by the following equation:

$$score_j = RI_j \oplus \sum_{j' \neq j} T_{jj'} \otimes RI_{j'},\ j = 1,\ldots,m. \quad (2)$$

The final score is defuzzified in order to obtain a final crisp score:

$$S_j = (l + 2m + u)/4 \quad (3)$$

The ECs are ranked in decreasing order of crisp scores. A higher score of EC implicates a higher priority to consider and thus, a higher importance to attribute.

IV. Classification of IT for CPD

Technological change, especially in PD and collaborative technologies domains, are increasingly rapid and hard to track. However, services offered by various systems do not transform in the same pace as the complexity level increases.

CPD systems are generally built on various infrastructures. Commercial software and academic projects based on these infrastructures are numerous to cite and easily outdated, therefore out of the scope of this research. Nevertheless, some systems and commercial packages, summarized in [9] and [22], can be a reference on the services offered by researchers and industry.

A. Requirements overview

CPD literature and industrial experts express similar opinions when it comes to technological requirements in CPD projects, although some differences may be observed. Li and Su [23] state that CPD environment should comprise *scalability, openness, heterogeneity, resources access and inter-operation, legacy codes reusability, and artificial intelligence* as features. According to Rodriguez and Al-Ashaab [9], common access of design information, collaborative visualization of the component, and collaborative design of the component are the requirements to be supported by collaborative technologies. Palacio et al. [14] classify SD requirements in four groups: *scale, uncertainty, interdependence, and communication.* These requirements form a starting point for both collaboration and development processes. Requirements of CSD, which can be viewed as CPD sub-domain, include *interaction*, *knowledge*, *awareness*, *coordination*, *communication*, and *control* [14].

These aspects are categorized in nine groups under the *Requirements* domain, each requirement followed by its label.

Communication (CA1) emerges as a principal requirement in IT planning to assure awareness [22]. *Project Management* (CA2) and *Knowledge Management* (CA3) are two essential requirements as stated in [1,3,9,24], which clearly suggest that these two requirements should be considered within any type of project, regardless of its collaborative aspect. Another important requirement while planning the technological infrastructure of CPD is the *product model* (CA4) itself. The technological infrastructure should comprise a system that enables the representation, visualization, modification of the product model. *Data Integration & Analysis* (CA5) requirement can be described as a mechanism to integrate data available on different sites from different collaborating teams and to analyze this data in a most efficient manner [25]. Accordingly, *Interoperability* (CA6) requirement emerges as a natural result of collaboration in order to assure diverse systems to work together.

Security (CA7) and privacy issues arise as CPD projects become a part of the business routine. This requirement implicates data protection as well as system back-up, as mentioned in [1]. Accordingly, defined by ISO 31000 as the effect of uncertainty on objectives, *Risk Management* (CA8) is a requirement to control uncertainties that may result in project failures. Lastly, CPD infrastructure requires *Technical Support* (CA9) given that collaborative infrastructure consisting of technology products may often necessitate maintenance and repair services.

The next section discusses the features presented by the various tools available in the technology arena. These features will be employed to respond to the aforementioned requirements.

B. System features overview

Nine requirement groups described in the previous section are met by various tools presented by commercial applications and academic researches. These tools are gathered in ten groups, labelled as *features* of CPD systems. Each feature is followed by its label.

Palacio et al. [14] state that technological infrastructure to meet the specified requirements should include features such as *communication service, mechanism to share and filter relevant information, mechanism to spot individual project progress, interaction mechanism for team members, status updates and tasks progress, search tool based on profile, status, and activity; synchronous and asynchronous communication*. PD oriented studies are also reviewed to support development process while technology planning. Sky and Buchal [26] categorize tools to support PD in six groups: *information gathering, drawing and design, analysis and evaluation, general documentation, planning and scheduling, synchronous workspace sharing*. Büyüközkan et al. [3] classify concurrent PD tools as *networking and management tools, modelling and analysis tools, predictive tools, and intelligent tools*.

Studies clearly emphasize the importance of communication tools. It is essential to assure coordination with ICT [1] and therefore communication tools are considered as primary features in a CPD system. Literature shows that synchronous and asynchronous communication tools are nearly always included in any collaborative system. *Synchronous communication tools* (EC1) assure real-time communication while spatially and temporally different communication is realized by *asynchronous communication tools* (EC2); which include e-mail, faxing, discussion boards, etc.

System integration mechanisms (EC2) are also widely studied in the literature. Some argue web-based interfaces to integrate various design models while others propose unification of modelling schemes [27]. *Project management tool* (EC4) is indispensable in a CPD project and it serves to control and coordinate the virtual team and their tasks [9]. *Product visualization* (EC4) is another feature of CPD systems. Collaborative visualization and collaborative design of the product allows teams to view, design, modify, mark-up, and measure the 3D virtual geometric model.

Document management tools (EC6) systems aim to store electronic documents and images, which enables engineering teams to create knowledge out of the information shared throughout the CPD project. *Content management tools* (EC7), serve to manage the workflow in collaborative environments.

Described as tools to keep track of history of a dataset [25], *Data Tracking & Analysis Tool* (EC8) enables the collaborating teams to make sense of the data they are handling. Data tracking is therefore important as it provides a detailed history of the data and the origin it generated from. *Archiving tools* (EC9) is also an important feature where large data is shared by distributed teams as storing, retrieving, and accessing the data are assured by archiving. It is important to be able to make use of the information created during the collaboration process. *Decision support tools* (EC10) become necessary at this stage, where a system is required to analyze all data and present an understandable report to assist decision makers' in their decision process.

Overall, ten system features are identified in response to the nine requirements of CPD projects.

V. IT PLANNING USING FUZZY QFD

Defining the requirements and the system features provides a better understanding of the current situation of CPD infrastructure. However, a planning methodology is required in order to map the aforementioned requirements into the features. HoQ diagram, the most recognized form of QFD, emerges as an appropriate planning tool. The translation of customer requirements into technical specifications becomes IT requirements for CPD mapped into CPD system features. Consequently, CAs are mapped into ECs in order to define how the system features respond to CPD requirements.

TABLE I. FUZZY SCALE FOR IMPORTANCE LEVELS

Scale for importance levels		
Linguistic variable	***Abbreviation***	***TFN***
Very low	VL	(0, 1, 2)
Low	L	(2, 3, 4)
Medium	M	(4, 5, 6)
High	H	(6, 7, 8)
Very high	VH	(8, 9, 10)
Scale for relationships		
Linguistic variable	***Abbreviation***	***TFN***
Strong	Θ	(7, 10, 10)
Moderate	O	(3, 5, 7)
Weak	▲	(0, 0, 3)
Scale for correlations		
Linguistic variable	***Abbreviation***	***TFN***
Strong positive	⊕	(3, 5, 7)
Positive	+	(0, 3, 5)
Negative	−	(-5, -3, 0)
Strong Negative	⊖	(-7, -5, -3)

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Our expert; an e-Business specialist, Knowledge Management Group leader, and CRM coordinator; is consulted for his industrial insight on the importance of requirements, requirement-system feature relationships, and system features correlations. He is asked to evaluate domains 3, 4, and 5 according to the scales presented in Table I.

The HoQ evaluation is displayed in Fig. 2. The expert evaluation, contrary to expectations, covers all pairwise relationships in Domain 4 and all pairwise correlations in Domain 5.

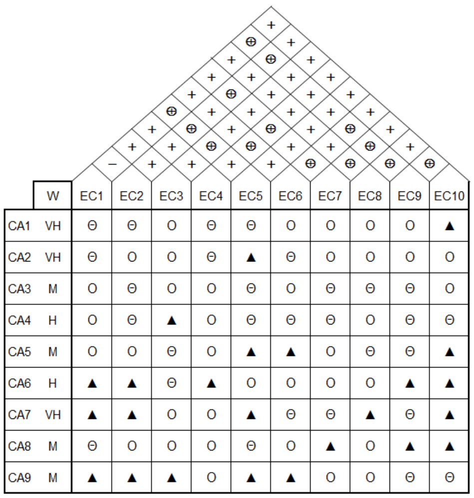

Figure 2 Expert judgments on weights, relationships and correlations

Fig. 2 lists the importance of the requirements. Then the mapping phase shows how these requirements are satisfied through the system features. Lastly, correlations between the system features are defined in order to observe their effect on each other.

These expert judgments are translated into TFNs according to the scales in Tables I. Priorities of system features are computed through equations (1) and (2). Final crisp priorities, displayed in Table II, are computed through equation (3). As a result, a priority vector is obtained for implementation of system features.

TABLE II. SYSTEM FEATURE PRIORITIES

	System Feature	**Priorities (Normalized)**
EC9	Archiving tools	0.122
EC7	Content management tools	0.119
EC5	Product visualization	0.106
EC6	Document management tools	0.105
EC8	Data tracking & analysis	0.098
EC4	Project management tool	0.098
EC10	Decision support tools	0.094
EC3	System integration mechanisms	0.090
EC2	Asynchronous communication tools	0.088
EC1	Synchronous communication tools	0.080

Final ranking of normalized priorities clearly suggest the importance of the archiving tools. This outcome can be interpreted as the importance of co-learning in CPD projects [1]. Archiving tools assure communication of the created information and sharing during collaboration efforts. Content management tools hold the second level of priority. This feature is also strongly connected with co-learning, whşch is a result of CPD. In a CPD project, product visualization tools rank as the third important system feature. This tool enables various engineering teams from various sites to conduct development process and therefore emerges as another high priority feature.

It is interesting to observe that communication tools (asynchronous and asynchronous) are the two system features with the least priorities. However, when combined, they emerge as the system feature with the most priority. This outcome can be linked to the fact that communication tools do not require high technology or high specification. Even the most basic communication tools can achieve the communication required in the CPD projects.

The outcome can be interpreted as an investment route for IT implementation at the beginning of a CPD project. This HoQ outcome aims to provide an understanding of implementation priorities from our expert's perspective.

CONCLUDING REMARKS

An essential part of CPD performance is IT; given that both the PD and the collaboration of various teams on different sites require a comprehensive technological infrastructure to support the communication as well as the integration of the firms. However, the rapid evolution of the IT complicates the forecasting and the planning of technological infrastructure.

The contribution of this study is two-fold. First, this paper proposes a set of technological requirements for CPD and a generic set of system features that includes tools and applications to respond to these requirements. On the other hand, a HoQ framework is employed to map the requirements to the system features. Importance of requirements, relationships between requirements and features, and correlations between system features included in the HoQ are evaluated by an industrial expert and Fuzzy QFD methodology is employed to interpret these evaluations.

Results show that system features associated with collaborative learning have the most priorities when planning technological infrastructure. However, it is apparent that all system features concur approximately to the same importance level. This can be interpreted as the need to cover all aspects of technological infrastructure within a CPD process. The outcome provides an implementation route for system features while considering IT infrastructure for CPD projects.

Further research includes extension of the current work through evaluations of different industrial experts in order to observe the differences in the priorities outcome according to industrial profile of the assessor. It is also anticipated to further develop the HoQ application in order to present a

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comprehensive planning methodology, considering additional inputs.

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