International Journal of Advance Research and Innovation
Vol. 3(4), Oct-Dec 2015, pp. 8-17
Doi: 10.51976/ijari.341503
www.gla.ac.in/journals/ijari

Article Info
Received: 05 Oct 2015 | Revised Submission: 20 Oct 2015 | Accepted: 28 Nov 2015 | Available Online: 15 Dec 2015

Identification, Selection and Evaluation of COTS Selection Criteria using Fuzzy Set Theory

Rakesh Garg, R. K. Sharma** and Kapil Sharma****

ABSTRACT

In the last decades, the development of the reliable and stable software with less development time and cost, has led to a great interest in CBSE (component based software engineering). The success of such component based systems mainly depends on the effective selection of COTS components among the various alternatives that meet the user's requirements. So, a set of predefined selection criteria must be obtained for the effective selection and evaluation of various COTS components. In this research paper, the identification of various criteria for the selection of COTS component is done, and then these selection criteria are ranked according to their local and global weights.

Keywords: *Commercial off-the-Shelf; Fuzzy Set Theory; Selection Criteria; Component Based Software Engineering.*

1.0 Introduction

A significant proportion of the IT portfolio now a day is comprised by the component based software development (CBSD). Component based software development focuses on the development of large software systems by integrating the already existing reusable software components named as COTS. Commercial-off-the-shelf (COTS) is defined as the software pieces that can be further reused by the software developers to build the new software systems.

The COTS products are readymade and can be used by the software developers "as it is" and can be easily installed and incorporated with the existing system components.

The use of COTS products provides many potential benefits as: (i) Reduction in development cost (ii) Reduction in development time and effort (iii) Improved quality of target software. In spite of many potential benefits, some disadvantages are also associated with the COTS products as (i) Incomplete knowledge of inner working code (ii) Compatibility issues (iii) Unavailability of correct and complete specifications.

Unlike the other software development approaches, the success of component based software engineering is dependent on the identification, selection and evaluation of the COTS components. So, before the integration of the various COTS components in the final software there is a need of to qualify adapt these components.

For the accurate evaluation of these COTS components, a set of the COTS selection criteria must be identified.

The rest of the paper is structured as follows: Section 2 review various COTS selection criteria available in open literature. The methodology of assigning priority weights to the identified criteria is explained in section 3.

Ranking procedure for the COTS selection criteria based on fuzzy set theory is described in section 4. Priority weights and results of ranking of the COTS selection criteria and sub-criteria are provided in section 5.

References used in the present research work are given at the end of the paper.

**Corresponding Author: Department of Computer Science & Engineering, Al-Falah School of Engineering & Technology, Faridabad, Haryana, India (E-mail: rkgarg06@gmail.com)*
***Department of Computer Science & Engineering, Al-Falah School of Engineering & Technology, Faridabad, Haryana, India*
****Department of Computer Science and Engineering, Delhi Technological University, Delhi, India*

2.0 Review of COTS selection criteria

COTS selection has become very crucial in the component based development approach for the developers and researchers.

A lot of research has been done by various researchers to find the COTS selection criteria. Bertoa and Vallecillo [1] proposed a quality model for the component based software development (CBSD) based on ISO 9126, that defines a set of quality attributes as Functionality, Reliability, Usability, Efficiency, Maintainability, Portability etc. and their associated metrics for the effective selection and evaluation of COTS components.

Wanyama and Homayoun [2] found that the COTS selection is a complex multi-criteria decision making (MCDM) problem characterized by uncertainty, complexity, multiple stakeholders and multiple objectives. In the contemporary work Rehman et al. [3] present vendor dependence as a major factor in COTS selection.

Huan-Jyh Shyur [4] presented cost, supplier's support, technological risk, closeness of fit to company's business, ease of implementation, flexibility to easy change as the company business change and system integration (CO, SS, TR, FB, EI, FC, SI) as the COTS selection criteria.

Neubauer and Stummer [5] solved the problem of COTS selection by categorizing the different COTS selection factors mainly in functional criteria, quality criteria (defect rate, performance, usability, security etc.), strategic criteria (cost, available time etc.) and domain and architectural criteria.

Wanyama and Far [6] had addressed the problem of COTS selection using reliability, maintainability, security, portability, compatibility, vendor ability, initial product price, initial hardware price, implementation costs, training costs, license conditions as selection criteria.

Basem Suleiman [7] has addressed the COTS selection problem using system integration interface, functionality aspects, COTS vendor maturity, conformity to system environment (consistency between system requirements, hardware, software application systems and COTS component infrastructure), budget, time, vendor support as selection criteria.

Ibrahim et al. [8] proposed the selection criteria for the COTS component such as usability, security, functionality, performance, recoverability and impact. Ravi chandran et al. [9] listed a large number of COTS selection attributes such as reliability, stability, portability, consistency, completeness, interface and structural complexity, understandability of software documents, security, usability, accuracy, compatibility, performance, serviceability and customizability.

Baharom et al. [10] introduced vendor characteristics such as vendor stability, vendor reputation, vendor supportability and organization characteristics as system platform, development environment, culture and financial characteristic for COTS component selection. Gupta et al. [11] used quality, cost, probability of failure on demand, average no. of invocations, no. of lines of code, execution time, delivery time and quality characteristics as selection criteria. Mittal and Bhatia [12] applied AHP technique for the COTS selection by considering the reusability as selection criteria. Faridi et al. [13] presented the COTS selection on the basis of software quality model ISO/IEC 25010. Faundes et al. [14] proposed PBEC-OTS technique by accounting six criteria as Coverage, Automation, Implementation, Cost, Collaboration, and Participation.

Kaur and Singh [15] used Promethee method for the COTS selection by considering performance, reliability, maintainability, cost and integrability as selection criteria. Khan et al. [16] presented a component based software engineering framework for software reusability. Shah et al. [17] presented various quality criteria as effectiveness, efficiency, satisfaction, safety and usability as component selection criteria. A review of different COTS component selection criteria [1-29] is given in table 1.

3.0 Methodology Adopted

In this research, Fuzzy set theory is used for the ranking of various COTS selection criteria. Fuzzy logic theory which was introduced by Zadeh [18] has proved to be essential for numerous applications. As compared to conventional scale in problems of researches exploratory in nature and where primary data is needed to be collected through surveys i.e. questionnaires, interviews, etc. It is capable to model the vagueness and impreciseness. In fuzzy set theory, the data is collected from the respondents in linguistic variables, qualitative in nature, i.e. Extremely Less Important, Very Less Important, Less Important, Important, More Important, Very More Important, Extremely More Important etc. these linguistic variable are then converted into crisp score, a single numerical value, through fuzzy numbers using membership functions.

The algebraic functions can easily be applied on fuzzy numbers. The details on conversion of linguistic variables of a seven point fuzzy scale into corresponding crisp score values is explained in Table 2.

Table 1: Review of COTS Component Selection Criteria

Criterion/ Sub-Criterion	Author(s)	Jung and Choi	Leung and Leung	Inbrane and Vallecillo	Beetoa and Vallecillo	Wanyama and Homayoun	Rehman et al.	Carvallo et al.	Cortellssa et al.	Sassi et al.	Huan-Jyh shyur	Mohamed et al.	Neubauer and Stummer	Wanyama and H. Far	Basem Suleiman	Rao and Rajesh	Ibrahim et al.	Kaur and Mann	Kwong et al.	Indumati et al.	Tang et al.	Ibrahim et al.	Ravichandran et al.	Baharom et al.	Gupta et al.	Gupta et al.
	Year	1999	2002	2002	2002	2005	2005	2006	2006	2006	2006	2007	2007	2008	2008	2009	2009	2010	2010	2011	2011	2011	2012	2012	2012	2013
Quality		Y											Y												Y	Y
Cost		Y					Y		Y		Y		Y	Y	Y	Y		Y		Y					Y	Y
Suitability				Y																						Y
Functionality			Y		Y					Y		Y	Y		Y				Y			Y				Y
Reliability					Y				Y					Y									Y			Y
Reusability					Y								Y								Y		Y			Y
Efficiency					Y																					Y
Maintainability					Y									Y												Y
Cohesion																			Y	Y						
Coupling																			Y	Y						
Compatibility														Y							Y		Y			
Recoverability																						Y				
Delivery Time									Y				Y												Y	
Interoperability																										Y
Compliance																										Y
Maturity																										Y
Operability																										Y
Testability																										Y
Adaptability																										Y
Install-ability																										Y
Replace-ability																										Y
Time Behavior																										Y
Resource Behavior																										Y
Conformance															Y											Y
Technological Risk											Y					Y										
Closeness of Fit											Y	Y				Y										
Ease of Implementation											Y					Y										
Flexibility to Change							Y				Y					Y		Y								Y
Development Environment																								Y		
POF on Demand																									Y	
Line of Code																									Y	
No. of Invocations																									Y	
Execution Time																									Y	
Customizability																							Y			
Schedule							Y																			
Multiple Objectives						Y																				
Impact																						Y				
Stability																							Y			
Consistency																							Y			
Completeness																							Y			
Interface Complexity						Y							Y										Y			
Understandability																							Y			Y
Accuracy																							Y			Y
Compatibility																							Y			
Serviceability																							Y			
Vendor Stability															Y									Y		

Table 2: Linguistic Terms Representation Using Triangular Fuzzy Numbers

Qualitative measures of selection criteria/sub-criteria (Linguistic Variables)	Fuzzy number	Membership function $\mu(x)$	Right score $\mu_R(M_1)$	Left score $\mu_L(M_1)$	Crisp score $\mu_T(M_1)$
Extremely Less Important	$M_1(0, 0, 0)$	$\mu_{M_1}(x) = 1, x = 0$	0	1	0
Very Less Important	$M_2(0, 0.1, 0.2)$	$\mu_{M_2}(x) = \begin{cases} (x-0)/(0,1) & 0 \le x \le 0.1 \\ (0.2-x)/(0,1) & 0.1 \le x \le 0.2 \end{cases}$	0.1818	0.9091	0.1364
Less Important	$M_3(0.2, 0.3, 0.4)$	$\mu_{M_3}(x) = \begin{cases} (x-0.2)/(0,1) & 0.2 \le x \le 0.3 \\ (0.4-x)/(0,1) & 0.3 \le x \le 0.4 \end{cases}$	0.3636	0.7273	0.3182
Important	$M_4(0.4, 0.5, 0.6)$	$\mu_{M_4}(x) = \begin{cases} (x-0.4)/(0,1) & 0.4 \le x \le 0.5 \\ (0.6-x)/(0,1) & 0.5 \le x \le 0.6 \end{cases}$	0.5455	0.5455	0.5
More Important	$M_5(0.6, 0.7, 0.8)$	$\mu_{M_5}(x) = \begin{cases} (x-0.6)/(0,1) & 0.6 \le x \le 0.7 \\ (0.8-x)/(0,1) & 0.7 \le x \le 0.8 \end{cases}$	0.7273	0.3636	0.6818
High/ Very More Important	$M_6(0.8, 0.9, 1)$	$\mu_{M_6}(x) = \begin{cases} (x-0.8)/(0,1) & 0.8 \le x \le 0.9 \\ (1-x)/(0,1) & 0.9 \le x \le 1 \end{cases}$	0.9091	0.1818	0.8636
Very high/ Extremely More Important	$M_7(1, 1, 1)$	$\mu_{M_7}(x) = 1, \quad x = 1$	1	0	1

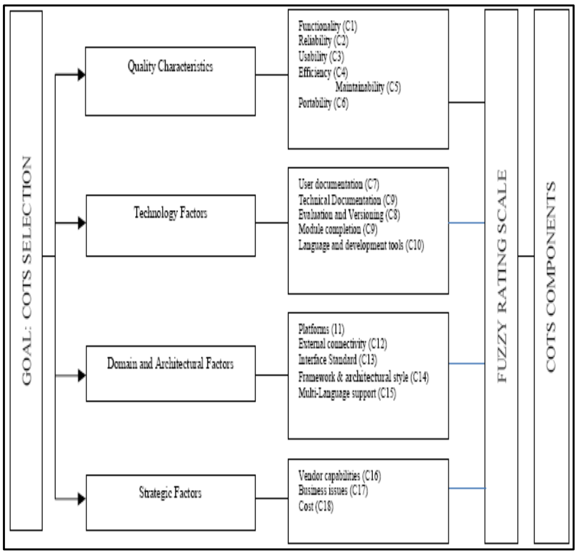
4.0 Ranking Procedure

In this section, a ranking procedure for the ranking of various COTS selection criteria based on their local and global weights is described as:

4.1 Ranking criteria: identification and selection

The COTS components can be compared by means of several criteria, collectively termed as ranking criteria. An exhaustive list of such ranking criteria available in open literature has been tabulated in previous section. The major emphasis of the researchers for the selection of COTS components is on the quality characteristics, cost, vendor issues etc. However, each of the ranking criteria relates to some particular aspect of the COTS considered important to the objective of present research work. Using the experience gained from the literature and peer group discussions, seventeen ranking criteria are identified and grouped in four major categories namely (i) Quality characteristics (ii) Technology factors (iii) Domain and architectural factors and (iv) Strategic factors. A hierarchical structure of these ranking criteria is given in Figure 1.

Fig 1: Hierarchal structure of COTS Selection Criteria



4.2 Experts identification and selection

There exists a lack of maturity in this field and it is impossible to identify secondary data in the open literature that could constitute the basis for ranking the various COTS selection criteria. Consequently, there is only an alternate to collect primary data and under such circumstances, reliance on expert opinion is the only optimal approach for collection of data.

A single expert is sufficient for an expert elicitation process if possesses infinite knowledge and never errs meaning thereby perfect in the field of specialization. The chances of making a mistake or due to limited and inadequacy of the knowledge, it is always better to have more than one expert. For the present research work, the researchers prepared a list of twenty five potential experts taking experts dependencies' into consideration. Finally, ten experts are selected based on their expertise, subject knowledge going through brain storming, experience and current position in academia/industry.

4.3 Questionnaire design

The present research is exploratory in nature. Questionnaire is considered to be the best way of collection of data in survey researches which are exploratory in nature. Since, no secondary data is available in the open literature and hence questionnaires are used to collect primary data. A questionnaire is designed to estimate the weights of the various COTS selection criteria identified in this research from the literature. The weights by the experts are provided on a seven point fuzzy scale. The questionnaire is designed in three parts: First part of each questionnaire contains a covering letter which explains the purpose of the research study and statement of confidentiality. Second part consists of demographic details e.g. name of the organization, field of expertise (software development, software design, software purchasing and procurement, etc.); length of experience, qualification and designation, etc. Third part of the questionnaire consists of assigning weights to the selection criteria of the COTS components on a predetermined seven point fuzzy scale.

4.4 Data collection

In this research, the data to calculate the weights for the various selection criteria is provided by the ten experts through a well designed questionnaire, then these linguistic terms are converted in triangular fuzzy numbers and corresponding crisp values by using table 2 as given in section 3.

A statistical analysis was performed on the data obtained from the experts using SPSS. The Cronbach's alpha value, so obtained, was more than 0.8 in case of importance of the ranking criteria. Such a value of Cronbach's alpha indicates higher reliability and internal consistency among the values assigned by the different experts. Aggregation of expert opinions is necessary irrespective of the method of aggregation i.e. Arithmetic or geometric averages being consistently better than the opinions of individual experts.

Keeping in consideration that all experts are equally competent, qualified and experienced, and no significant difference was observed in terms credibility and importance, hence all experts are weighted equally and arithmetic averaging aggregation method is adopted going through in-depth analysis of the responses of the experts.

The weights for the various selection criteria in linguistic terms on a seven point fuzzy scale provided by the ten experts are given in Appendix 1. The linguistic terms are converted into corresponding crisp scores on a scale of 0-1 and the average values of the experts rating are done using fuzzy aggregation methods.

The corresponding crisp scores and average aggregation values are provided in Table 3.

Table 3: Crisp Scores and Average Values of Priority Weights of COTS Selection Criteria

S. No.	Criterion/Sub-Criterion	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	Average
A	Quality Characteristics											
1	Functionality											
1.1	Accuracy	1.00	1.00	1.00	0.86	0.86	0.68	1.00	1.00	0.68	0.86	0.895
1.2	Compliance	0.68	0.50	0.50	0.86	0.50	0.68	0.86	0.50	0.50	0.68	0.627
1.3	Interoperability	0.68	0.50	0.86	0.86	0.50	0.68	0.86	0.68	0.50	0.50	0.664
1.4	Security	1.00	1.00	0.68	0.86	0.68	0.68	0.86	1.00	0.68	0.86	0.832
1.5	Suitability	0.50	0.50	0.50	0.68	0.31	0.50	0.68	0.50	0.50	0.68	0.536
2	Reliability											
2.1	Fault Tolerance	0.68	0.50	0.86	0.68	0.86	0.50	0.50	0.68	0.68	0.86	0.682
2.2	Maturity	0.50	0.31	0.68	0.50	0.50	0.31	0.68	0.31	0.31	0.50	0.464
2.3	Recoverability	0.50	0.68	1.00	0.86	0.68	0.68	0.50	1.00	0.50	0.50	0.691
3	Usability											
3.1	Learn-ability	0.31	0.50	0.13	0.31	0.50	0.13	0.13	0.00	0.31	0.31	0.268
3.2	Operability	0.86	1.00	0.68	0.68	0.50	0.68	0.86	0.86	0.68	1.00	0.782
3.3	Understandability	0.68	0.68	1.00	0.68	0.50	0.68	0.50	0.86	0.50	0.68	0.677
4	Efficiency											
4.1	Resource Behavior	0.50	0.31	0.86	0.50	0.68	0.31	0.50	0.50	0.31	0.68	0.518
4.2	Time Behavior	0.68	0.50	0.86	0.86	0.68	0.68	0.50	0.68	0.50	0.50	0.645
5	Maintainability											
5.1	Analyzability	0.31	0.31	0.68	0.31	0.50	0.50	0.68	0.50	0.31	0.31	0.445
5.2	Changeability	0.50	0.50	0.86	0.68	0.50	0.50	0.68	0.31	0.50	0.31	0.536
5.3	Stability	1.00	0.68	0.86	0.68	0.68	0.86	1.00	0.86	0.86	0.68	0.818
5.4	Testability	0.86	1.00	1.00	0.68	0.86	0.68	0.86	0.86	1.00	1.00	0.882
6	Portability											
6.1	Adaptability	0.68	0.68	0.86	0.68	0.50	0.68	0.68	0.86	0.86	0.50	0.700
6.2	Conformance	0.50	0.50	0.50	0.31	0.68	0.50	0.31	0.31	0.50	0.50	0.464
6.3	Installability	0.68	0.86	0.86	0.50	0.50	0.68	0.68	0.86	0.50	0.68	0.682
6.4	Replaceabilty	0.31	0.50	0.31	0.31	0.13	0.31	0.50	0.31	0.31	0.50	0.355
B	Technology Factors											
7	User Documentation	0.68	0.68	0.50	0.31	0.50	0.50	0.68	0.31	0.31	0.50	0.500
8	Technical Documentation	0.86	0.68	0.86	0.50	0.50	0.50	0.68	0.86	0.86	0.68	0.700
9	Evaluation and Versioning	0.50	0.68	1.00	0.68	0.86	0.68	0.68	0.50	0.86	0.68	0.714
10	Module completion	0.68	0.68	0.68	0.50	0.50	0.31	0.68	0.50	0.68	0.31	0.555

11	Language and Development Tools	0.31	0.68	0.86	0.68	0.68	0.50	0.31	0.31	0.50	0.68	0.555
C	Domain And Architectural Factors											
12	Platforms	0.68	0.50	0.86	0.50	0.68	0.86	0.31	0.50	0.68	0.68	0.627
13	External Connectivity	0.68	0.68	0.86	0.68	0.50	0.50	0.68	0.86	0.68	0.50	0.664
14	Interface Standard	0.86	0.68	0.68	0.50	0.50	0.68	0.86	0.86	0.68	0.50	0.682
15	Framework and Architectural Style	0.68	0.68	0.86	0.68	0.86	0.86	0.50	0.86	0.68	0.68	0.736
16	Multi-Language Support	0.31	0.50	0.86	0.50	0.68	0.31	0.31	0.50	0.68	0.50	0.518
D	Strategic Factors											
17	Vendor Capabilities											
17.1	Market Trends	0.50	0.31	0.86	0.50	0.50	0.68	0.31	0.31	0.50	0.68	0.518
17.2	Training and Support	0.68	0.31	0.50	0.50	0.50	0.68	0.68	0.68	0.31	0.50	0.536
17.3	Vendor Reputation	0.68	0.50	0.68	0.31	0.31	0.50	0.68	0.50	0.50	0.31	0.500
17.4	Vendor Location	0.50	0.50	0.68	0.50	0.50	0.50	0.31	0.68	0.31	0.50	0.500
17.5	R & D Technology	0.50	0.50	0.31	0.50	0.50	0.31	0.68	0.31	0.31	0.31	0.427
17.6	Financial Condition	0.86	0.68	0.68	0.50	0.50	0.68	0.86	0.68	0.68	0.50	0.664
17.7	Implementation and Serviceability	0.68	0.68	0.86	0.50	0.50	0.50	0.50	0.68	0.86	0.68	0.645
18	Business Issues											
18.1	Licensing Arrangements	0.86	0.86	0.50	0.68	0.68	0.50	0.86	0.68	0.50	0.50	0.664
18.2	Organizational Policies	1.00	0.68	0.86	0.68	0.68	0.68	1.00	0.68	0.86	0.68	0.782
18.3	Risk factors	0.86	0.86	0.68	0.86	0.86	0.86	0.68	0.86	0.68	0.68	0.791
19	Cost											
19.1	Production Cost	0.68	0.68	1.00	0.86	0.68	0.86	0.86	0.68	0.50	0.68	0.750
19.2	Installation and Implementation Cost	0.86	0.68	0.68	0.50	0.68	0.50	0.86	0.68	0.50	0.50	0.645
19.3	License Cost	0.86	0.50	0.31	0.50	0.50	0.68	0.31	0.31	0.50	0.50	0.500
19.4	Upgradation And Maintenance Cost	0.68	0.50	0.86	0.50	0.68	0.68	0.50	0.86	0.86	0.50	0.664

4.5 Calculation of criteria weights

The weights (local and global) of the ranking criteria are estimated using the adopted methodology as explained in previous sections and are summarized in Table 4.

Table 4: Weights (Local and Global) for Ranking Criteria

S. No.	Criterion/Sub-Criterion	Local Wt.	Global Wt.	S. No.	Criterion/Sub-Criterion	Local Wt.	Global Wt.
Quality Characteristics		0.470	0.470	Domain & architectural factors		0.115	0.115
C1	Functionality	0.270	0.127	C12	Platforms	0.194	0.022
C2	Reliability	0.131	0.066	C13	External connectivity	0.206	0.024
C3	Usability	0.131	0.062	C14	Interface standard	0.211	0.024
C4	Efficiency	0.088	0.042	C15	Framework & architectural style	0.228	0.026
C5	Maintainability	0.204	0.096	C16	Multi-language support	0.161	0.019
C6	Portability	0.167	0.079	Strategic Factors		0.307	0.307
Technology Factors		0.108	0.108	C17	Vendor capabilities	0.442	0.135
C7	User Documentation	0.165	0.018	C18	Business Issues	0.261	0.080
C8	Technical Documentation	0.232	0.025	C19	Cost	0.298	0.091
C9	Evaluation and versioning	0.236	0.026				
C10	Module completion	0.184	0.020				
C11	Language and development tools	0.184	0.020				

4.6 Ranking of criteria weights

Finally, the various selection criteria and sub-criteria identified in this research are ranked on the basis of their global weights as given in tables 5 and 6 respectively.

Table 5: Ranking of Selection Criteria

S. No.	Criterion	Global Weight	Ranking
1	Quality Characteristics	0.470	1
2	Technology Factors	0.108	4
3	Doman and Architectural Factors	0.115	3
4	Strategic Factors	0.307	2

Table 6: Ranking of Selection Sub-Criteria

S. No.	Sub-Criterion	Global Weight	Ranking
1	Vendor capabilities	0.135	1
2	Functionality	0.127	2
3	Maintainability	0.096	3
4	Cost	0.091	4
5	Business Issues	0.08	5
6	Portability	0.079	6
7	Reliability	0.066	7
8	Usability	0.062	8
9	Efficiency	0.042	9
10	Evaluation and versioning	0.026	10
11	Framework & architectural style	0.026	11
12	Technical Documentation	0.025	12
13	External connectivity	0.024	13
14	Interface standard	0.024	14
15	Platforms	0.022	15
16	Module completion	0.02	16
17	Language and development tools	0.02	17
18	Multi-language support	0.019	18
19	User Documentation	0.018	19

5.0 Results and Conclusion

According to the methodology adopted in the illustrated example, the higher value of global weight of selection criteria depicts the better ranking. The comparative rankings of all four criteria namely quality characteristics, technology factors, domain and architectural factors and strategic factors are given in Fig 2.

Fig 2: Ranking of COTS Selection Criteria

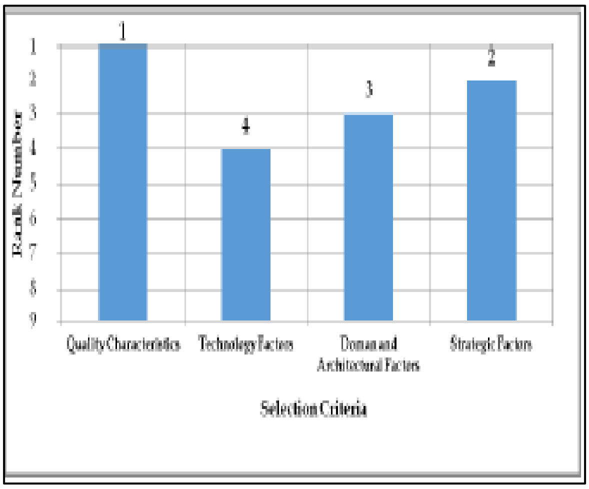


Figure depicts that 'Quality Characteristics' selection criteria is ranked at number 1 based on global weights and is followed by 'Strategic Factors' and 'Domain and Architectural Factors'. 'Technology Factors' selection criterion is ranked at the last position or at number 4. Ranking of sub-criteria based on their global weights is shown in figure 3.

Fig 3: Ranking of COTS Selection Sub-Criteria

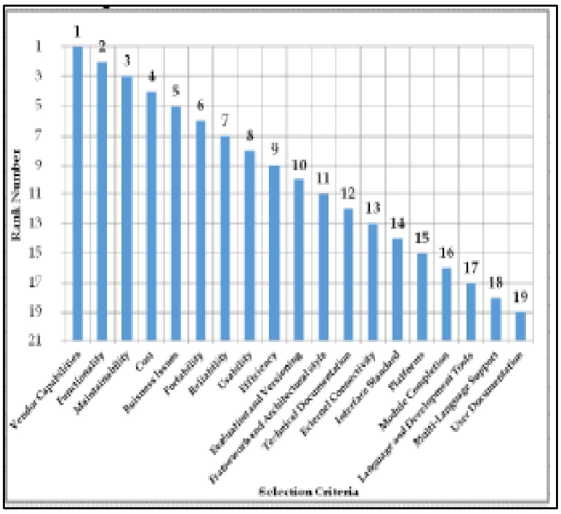


Figure depicts that 'Vendor Capabilities' is ranked at number 1 followed by 'Functionality' at number 2 and 'Maintainability' at number 3. The 'User Documentation' selection criterion is of least importance and ranked at number 19 or at last position.

From the above discussions, it is well established that expert opinion is a better method to determine the priority weights of the various COTS selection criteria and subcriteria. Fuzzy method is suitable to overcome the fuzziness of the data and vagueness of the mind while estimating the priority weights of the criteria or sub-criteria.

References

[1] F. Manuel, Y Bertoa, Antonio Vallecillo, Quality Attributes for COTS Components, 2002

[2] Tom Wanyama, and BehrouzHomayoun Far, Towards Providing Decision Support for COTS Selection, Canda, IEEE, 0-7803-8886-0/05 CCECE/CCGEI, Saskatoon, 2005.

[3] Maree Mujeeb-u-Rehman, Xiaohu Yang, Jinxiang Dong and Memon Abdul Ghafoor, Prioritized Selecting COTS Vendor in cots-based software development process, China, IEEE, 0-7803-8886-0/05 CCECE/CCGEI, Saskatoon, 2005.

[4] Huan-JyhShyur, COTS evaluation using modified TOPSIS and ANP, Applied Mathematics and Computation, 177, 2006, 251–259

[5] Thomas Neubauer and Christian Stummer, Interactive Decision Support for Multi-objective COTS Selection, IEEE, Proceedings of the 40th Annual Hawaii International Conference on System Sciences (HICSS'07) 0-7695-2755-8/07, 2007.

[6] Tom Wanyama and Behrouz H. Far, AN EMPIRICAL STUDY TO COMPARE THREE METHODS FOR SELECTING COTS SOFTWARE COMPONENTS, International Journal of Computing and ICT Research, 1(2), 2008, 34 - 46

[7] Basem Suleiman, Commercial-Off-The-Shelf Software Development Framework, Australia, IEEE, 19th Australian Conference on Software Engineering 1530- 0803/08 DOI 10.1109/ASWEC.2008.73, 2008.

[8] Hamdy Ibrahim, Behrouz H. Far and Armin Eberlein, Tradeoff and Sensitivity Analysis of a Hybrid Model for Ranking Commercial Off-The-Shelf Products, UAE, 16th Annual IEEE International Conference and Workshop on the Engineering of Computer Based Systems, 978-0-7695-3602-6/09, DOI 10.1109/ECBS.2009.47.

[9] K. S. Ravichandran, P. Suresh, K. R. Sekr, ANFIS Approach for Optimal Selection of Reusable Components, India, Research Journal of Applied Sciences, Engineering and Technology, 4(24), 2012, 5304-5312

[10] Fauziah Baharom, Feras Tarawneh, Jamaiah Hj. Yahaya, AzidaZainol, NurnasranPuteh, HaslinaMohd, NoridaMuhdDarus, ZaharinMarzuki Matt and AzmanYasin, The Vendor and User Organizations Characteristics for COTS Software Evaluation and Selection, Malaysia, Knowledge Management International Conference (KMICe), 2012

[11] P. Gupta, Hoang Pham, Mukesh Kumar Mehlawat, Shilpi Verma, A Fuzzy Optimization Framework for COTS Products Selection of Modular Software Systems, International Journal of Fuzzy Systems, 15(2), 2013

[12] Framework for Evaluating and Ranking the Reusability of COTS Components based upon Analytical Hierarchy Process, Sonu Mittal, Pardeep kumar Bhatia, International journal of innovations in engineering and technology, 2(4), 2013

[13] M. Shakeel Faridi, Zahid Javed, M. Haris Abid, Mudassar Ahmed, Md Asri Bin Ngadi, IROTS: A Proposed COTS evaluation & selection methodolgy for component based software engineering in under developemnt countries, 2nd International Conference on Advances in Computer Science and Engineering (CSE 2013)

[14] Maria Jesus Faundes, Hernan Astudillo and Bernhard Hitpass, Process based evaluation and comarison of OTS software alternatives, Federated Conference on Computer Science and Information Systems 2013.

[15] Kulbir Kaur, Harshpreet Singh, Quantifying COTS Components Selection using Multi Criteria Decision Analysis Method PROMETHEE, Global Journal of Computer Science and Technology: Software & Data Engineering, 2014

[16] Adnan Khan, Khalid Khan, Muhammad Amir, M. N. A. Khan, Shaheed Zulfikar Ali, A component-based framework for software reusability, International Journal of Software Engineering and Its Applications, 8(10), 2014, 13-24

[17] Shah Nazir, Sajid Anwar, Sher Afzal Khan,Sara Shahzad, Muhammad Ali, Rohul Amin, Muhammad Nawaz, Pavlos Lazaridis, John Cosmas, Software component selection based on quality criteria using analytic network process,. Abstract and Applied Analysis, 2014

[18] Ho-Won Jung, Byoungju Choi, Optimization models for quality and cost of modular software systems, South Korea, European Journal of Operational Research, 112, 1999, 613-619

[19] P. Gupta, Mukesh Kumar Mehlawat and ShilpiVerma, COTS selection using fuzzy interactive approach, India, Springer, 2012

[20] R. V. Rao, T. S. Rajesh, Software Selection in Manufacturing Industries Using a Fuzzy Multiple Criteria Decision Making Method, PROMETHEE, Surat, India,Intelligent Information Management, 2009, 1, 159-165.

[21] Arvinder Kaur and Kulvinder Singh Mann, Component Selection for Component based Software Engineering, International Journal of Computer Applications (0975 – 8887), 2(1), 2010

[22] Indumati, Vijay M. Ghantasalaand P. C Jha, Optimal Component Selection of COTS based Modular Software System under Cohesion & Coupling Quality Metrics with Budgetary Constraint, Proceedings of the 5th National Conference; INDIA Com, 2011.

[23] Luis Iribarne, Jos´e M. Troya and Antonio Vallecillo, Selecting Software Components with Multiple Interfaces, IEEE, Proceedings of the 28th Euromicro Conference (EUROMICRO'02) 1089-6503/02, 2002

[24] R. P. Karl, H. Leung, Hareton K. N. Leung, On the efficiency of domain-based COTS product selection method, China,

Information and Software Technology, 44, 2002, 703–715

[25] Sihem Ben Sassi, Lamia Labed, Jilani Henda Hajjami, Ben Ghezala, Towards a COTS-Based Development Environment, Tunisia, IEEE, Proceedings of the Fifth International Conference on Commercial-off-the-Shelf (COTS)-Based Software Systems (ICCBSS 2006) 0- 7695-2515-6/06, 2006

[26] Abdallah Mohamed, Guenther Ruhe and Armin Eberlein, COTS Selection: Past, Present, and Future, Canada, IEEE, Proceedings of the 14th Annual IEEE International Conference and Workshops on the Engineering of Computer-Based Systems (ECBS'07) 0-7695-2772-8/07.

[27] C. K. Kwong, L. F. Mu, J. F. Tang, X. G. Luo, Optimization of software components selection for component-based software system development, China, , Computers & Industrial Engineering 58 (2010) 618–624.

[28] J. F. Tang, L.F. Mu, C. K. Kwong, X.G. Luo, An optimization model for software component selection under multiple applications development, China, European Journal of Operational Research, 212, 2011, 301–311

[29] G. Grau, J. P. Carvallo, X. Franch, C. Quer, Des COTS: A Software System for Selecting COTS Components," in EUROMICRO'04, Rennes, France, 2004, 118-126.

[30] Hamdy Ibrahim, Abdel-Halim H. Elamy, Behrouz H. Far, Armin Eberlein, Un HOS: A Method for Uncertainty Handling in Commercial Off-The-Shelf (COTS) Selection, International Journal of Energy, Information and Communications, 2(3), 2011

APPENDIX – 1

Priority weights of COTS selection criteria and sub-criteria assigned by Experts in linguistic terms

S. No.	Criterion/Sub-Criterion	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10
A	Quality Characteristics										
1	Functionality										
1.1	Accuracy	EMI	EMI	EMI	VMI	VMI	MI	EMI	EMI	MI	VMI
1.2	Compliance	MI	I	I	VMI	I	MI	VMI	I	I	MI
1.3	Interoperability	MI	I	VMI	VMI	I	MI	VMI	MI	I	I
1.4	Security	EMI	EMI	MI	VMI	MI	MI	VMI	EMI	MI	VMI
1.5	Suitability	I	I	I	MI	LI	I	MI	I	I	MI
2	Reliability										
2.1	Fault Tolerance	MI	I	VMI	MI	VMI	I	I	MI	MI	VMI
2.2	Maturity	I	LI	MI	I	I	LI	MI	LI	LI	I
2.3	Recoverability	I	MI	EMI	VMI	MI	MI	I	EMI	I	I
3	Usability										
3.1	Learnability	LI	I	LI	LI	I	VLI	LI	ELI	LI	LI
3.2	Operability	VMI	EMI	MI	MI	I	MI	VMI	VMI	MI	EMI
3.3	Understandability	MI	MI	EMI	MI	I	MI	I	VMI	I	MI
4	Efficiency										
4.1	Resource Behavior	I	LI	VMI	I	MI	LI	I	I	LI	MI
4.2	Time Behavior	MI	I	VMI	VMI	MI	MI	I	MI	I	I
5	Maintainability										
5.1	Analyzability	LI	LI	MI	LI	I	I	MI	I	LI	LI
5.2	Changeability	I	I	VMI	MI	I	I	MI	LI	I	LI
5.3	Stability	EMI	MI	VMI	MI	MI	VMI	EMI	VMI	VMI	MI
5.4	Testability	VMI	EMI	EMI	MI	VMI	MI	VMI	VMI	EMI	EMI
6	Portability										
6.1	Adaptability	MI	MI	VMI	MI	I	MI	MI	VMI	VMI	I
6.2	Conformance	I	I	I	LI	MI	I	LI	LI	I	I
6.3	Installability	MI	VMI	VMI	I	I	MI	MI	VMI	I	MI
6.4	Replaceabilty	LI	I	LI	LI	VLI	LI	I	LI	LI	I
B	Technology Factors										
7	User Documentation	MI	MI	I	LI	I	I	MI	LI	LI	I
8	Technical Documentation	VMI	MI	VMI	I	I	I	MI	VMI	VMI	MI
9	Evaluation and Versioning	I	MI	EMI	MI	VMI	MI	MI	I	VMI	MI
10	Module completion	MI	MI	MI	I	I	LI	MI	I	LI	LI
11	Language and Development Tools	LI	MI	VMI	MI	MI	I	LI	LI	I	MI
C	Domain And Architectural Factors										
12	Platforms	MI	I	VMI	I	MI	VMI	LI	I	MI	MI
13	External Connectivity	MI	MI	VMI	MI	I	I	MI	VMI	MI	I
14	Interface Standard	VMI	MI	MI	I	I	MI	VMI	VMI	MI	I
15	Framework and Architectural Style	MI	MI	VMI	MI	VMI	VMI	I	VMI	MI	MI
16	Multi-Language Support	LI	I	VMI	I	MI	LI	LI	I	MI	I
D	Strategic Factors										
17	Vendor Capabilities										
17.1	Market Trends	I	LI	VMI	I	I	MI	LI	LI	I	MI
17.2	Training and Support	MI	LI	I	I	I	MI	MI	MI	LI	I
17.3	Vendor Reputation	MI	I	MI	LI	LI	I	MI	I	I	LI
17.4	Vendor Location	I	I	MI	I	I	I	LI	MI	LI	I
17.5	R & D Technology	I	I	LI	I	I	LI	MI	LI	LI	LI
17.6	Financial Condition	VMI	MI	MI	I	I	MI	VMI	MI	MI	I
17.7	Implementation and Serviceability	MI	MI	VMI	I	I	I	I	MI	VMI	MI
18	Business Issues										
18.1	Licensing Arrangements	VMI	VMI	I	MI	MI	I	VMI	MI	I	I
18.2	Organizational Policies	EMI	MI	VMI	MI	MI	MI	EMI	MI	VMI	MI
18.3	Risk factors	VMI	VMI	MI	VMI	VMI	VMI	MI	VMI	MI	MI
19	Cost										
19.1	Production Cost	MI	MI	EMI	VMI	MI	VMI	VMI	MI	I	MI
19.2	Installation and Implementation Cost	VMI	MI	MI	I	MI	I	VMI	MI	I	I
19.3	License Cost	VMI	I	LI	I	I	MI	LI	LI	I	I
19.4	Upgradation And Maintenance Cost	MI	I	VMI	I	MI	MI	I	VMI	VMI	I