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Framework for estimating reliability of COTS component based upon Hierarchical Model for Reliability Estimation (HMRE)

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Abstract: Component Based Software System (CBSS) is an emerging approach for building complex software. It is made up of COTS component which is build by third party. It creates independent and pre- defined components and then integrates these components according to customers need to make a new whole software system. There are so many available COTS component in the market. Reliability is one of the most important quality attribute of the software. The main task for developer or integrator is how to select the COTS component which is highly reliable. There is large number of criteria for estimating reliability which includes component usage ratio, reusability, application complexity, operational profile, component dependency. In this paper, these five criteria are reviewed and a new framework Hierarchical Model for Reliability Estimation (HMRE) is proposed. This model selects the reliability criteria and estimates the reliability of COTS component. The application of this framework is illustrated by an example.

Keywords: COTS component, reliability, component usage ratio, reusability, application complexity, operational profile, component dependency, Hierarchical Model for Reliability Estimation (HMRE).

I. INTRODUCTION

Component Based Software System is an emerging approach for constructing and designing large complex software system. This approach relies on the idea of reusability. Reusability is the process of creating a new software system from the existing software rather than building them from scratch [1]. The aim of component based software system is to build a large software system by integrating commercial-off-the-shelf (COTS) components. COTS components are the reusable entities whose source code is not available. COTS components are the software that provides distinct functionality. It reuses the ready-made software package that are already tested and validated. It can be easily interoperated into existing system without need for customization. It is easily available for sale in market offered by vendors. The ultimate benefits of COTS-based software are it reduces the design and implementation of software, development cost, effort and time and improves the reliability, reusability and flexibility of software. Currently, the building of software with prefabricated COTS component is one of the leading concepts in the software development. This approach selects the appropriate pre-fabricated COTS component and then integrates them with software architecture.

Reliability is the probability of failure free operations. It is the ability to do intended work within a given period of time. Therefore reliability can be defined as "the probability of a failure free operation of software within a specified period of time in a specified environment" [2]. Reliability is an operational factor; it can only be measured by execution. Reliability can be expressed on a scale from 0 to 1. If the reliability of system is 1 it indicates that it is highly reliable software. Software reliability depends on reusability because it is directly proportional to reusability. So, reliability is one of the major characteristics in selecting the best reusable off-the-shelf components. Estimating the reliability of overall system is function of individual reliability of components.

Hence, the major task is to estimate the reliability of individual COTS components. In this paper, we discuss six important factors that are essential to estimate the component reliability. After estimating the component reliability we can prioritize that which COTS component reliability is best, that is which component is highly reliable among all the components.

II. LITERATURE REVIEW

The idea of software component was first presented by Douglas Mcllroy in his paper titled *Mass Produced Software Components* in 1968. The definition of Component Based Software Engineering (CBSE) is, it is a process that emphasizes the design and construction of computer-based systems using reusable software "components" [3]. Szyperski defines component as it is a compositional unit with specified interfaces and context dependencies [4]. The idea of component based reliability analysis received a great deal of attention from the mid to late 1990s.

In 1999 William W. Everett described an approach for component based reliability analysis. In his approach reliability was analyzed at the earlier in the software development life cycle. He proposed model parameters which estimate the reliability of software components [5]. In 2000 Chandra M. R. Kintala, Reinhard P.K lemm and Martin Kappes proposed a model of estimation of component based reliability. This model used finite state machine which was associated with component reliability that expresses the overall software reliability. By using this model reliability of CBS can be calculated accurately without a need of algorithm by using finite state machine [6].

In 2001, Chin-Yu Huang and Michael R.Lyu proposed an approach that was based on Markov model. It assumed that software components are heterogeneous and components transition follows a discrete time by using Markov process [7]. In 2004 Sherif Yacoub , Bojan Cukic and Hany H.Ammar were proposed a new analytical approach for estimation component reliability named as Scenario Based Reliability Analysis (SBRA). It is a stack based algorithm. It analyzes the impact of different parameters on reliability and then determines which of the component affects on the reliability of whole system [8].

In 2003, Fan Zhang et al. [9] proposed a new technique named as architecture based reliability model which analyze the estimation of CBS reliability. It analyzes reliability of component at the design phase of software development. It includes fault propagation as a parameter. This model has three sub approaches: state-based approach, path-based approach and additive model.

In 2004, Yacoub, S., Cukic, B., and Ammar, H., proposed a model for reliability analysis named as "Scenario based reliability analysis approach for component based systems" [10]. Using scenario a component dependency graph (CDGs) is constructed which captures sequence diagrams. Based on CDG a reliability analysis algorithm is developed to estimate the system reliability. This model is also proposed for distributed complex system.

In 2008, Dong, W., Huang, N., Ming, Y proposed a mathematical model for estimating CBSS reliability [11]. It introduces a complex relationship of components by using Markov model and then determines which component has large impact on system's reliability. Then a new tool is developed to calculate the software reliability.

In 2009, Goswami V., Acharya, Y.B., proposed a CBS reliability analysis approach named as "Method for reliability estimation of COTS components based software systems" [12]. This approach used reliability factor component usage ratio which is the ratio of execution time of component over execution time for overall CBSS system. It is used in real time application.

In 2010, soft computing technique was used for estimating CBS reliability. It was proposed by Sasikumar, Punnekkat, Dimov and Aleksandar named as "Fuzzy reliability model for component-based software systems" [13]. This technique is based on fuzzy logic and probability theory. These approaches solves the uncertainty aspect by using fuzzy sets and describe the reliability of software components.

III. CRITERIA FOR ESTIMATING RELIABILITY OF COTS COMPONENT

Reliability estimation of the software is the assessment of current value of the factors that affects that component. Applications related parameters are fault tolerance, failure rate, repair rate, mean time between failure, flexibility, safety, security, testability, availability, maintainability. Some significant component based parameters that are discussed in this paper are component usage ratio, application complexity, operational profile, component dependency and reusability.

A. *Component Usage Ratio*

Component usage ratio is the ratio of execution time of component over the total execution time of software [14]. The value for component usage ratio should be in between 0 and 1. Individual component usage ratio weights its impact on the overall software reliability. Higher the impact factor of the component, frequently executed component. In general, the component which is frequently executed has the greater impact on the overall software system.

$$\text{Reliability} \propto \text{Component Usage Ratio}$$

B. *Application Complexity*

Application complexity of a component can be defined as the number of component executed in that application and the interaction between the components. As the number of executed component increases, the application will become more complex. If the application is complex, its reliability will reduce [14]. Therefore, application complexity is inversely proportional to its reliability.

$$\text{Reliability} \propto 1/\ \text{Application Complexity}$$

C. *Operational Profile*

Operational profile is a quantitative characteristic of software development that tells how the component is used in the system. It is a complete set of operations with their probabilities of occurrence [15]. The OP for any component describes the no. of inputs supplied to the component. Reliability of component may vary for different operational profiles.

$$\text{Reliability} \propto \text{Operational Profile}$$

D. *Component Dependency*

In software, components are connected to other components to form large complex software. One component is dependent on other component to perform their function. Output of one component serves as an input for the other component [16]. So, dependency plays an important role in estimating the reliability of component. As the component dependency increases software reliability decreases. Flow of information connecting software component, their interaction and their function can be evaluated by dependency matrix.

$$\text{Reliability} \propto 1/\ \text{Component Dependency}$$

E. *Reuasability*

Reusability is a factor for estimating component reliability because components that have been used in many applications called more reliable [17]. Hence, the reliability of a component is directly proportional to its reusability.

$$\text{Reliability} \propto \text{Component Reusability}$$

Table I. COTS component reliability criteria and related metrics

S. No.	*Reliability Factors*	*Metric*
1.	Operational Profile	Reliability ∝ Operational Profile
2.	Application Complexity	Reliability ∝ 1/ Application Complexity
3.	Component Dependency	Reliability ∝ 1/ Component Dependency
4.	Component Reusability	Reliability ∝ Reusability

5.	Component Usage Ratio	Reliability ∝ Component Usage Ratio

For all the reliability metrics values must be lies between 0 and 1. Value 1 will be considered as the highest reliability value. These values can be used for estimating the reliability of COTS component in the proposed framework.

IV. THE PROPOSED FRAMEWORK

The criteria described in previous section have different characteristics and properties that affects on estimating the reliability of COTS component. The value of these criteria is not sufficient to estimate components reliability. Now, the main question here is how the COTS component reliability is estimated by using these criteria associated with the component. Thus, there is a need for an approach that can integrate and correlate these criteria to estimate the reliability of off-the-shelf components.

The solution for this question is a proposed framework for estimating component reliability using Hierarchical Model for Reliability Estimation (HMRE). It is a multi decision making approach. The aim of HMRE is: (i) it helps the developer or integrator to choose the best alternatives; (ii) it provides a graphical representation of criteria's associated with the components; (iii) it prioritizes the criteria of selection; (iv) it assigns weights to the criteria of selection; (v) it ranks the alternatives and selects the best one.

HMRE provides a hierarchical structure of decision making problem to understand the problem and simplify them. This technique includes mathematical calculations, graphical representation and number of pair wise comparisons, thus it is a time-consuming technique. This method is easy to use and understand. It is one of the best approaches because of its flexibility and accuracy in the result.

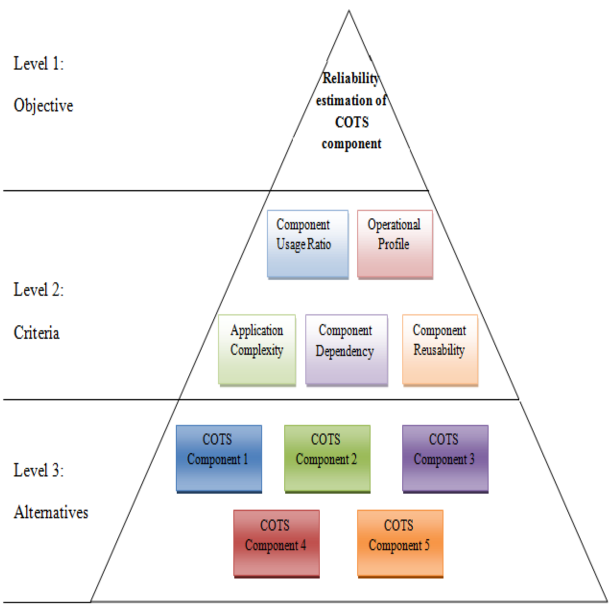

Figure 1: Hierarchical Model for Reliability Estimation (HMRE)

V. ILLUSTRATION BY AN EXAMPLE

The above method is illustrated by an example. Let us consider a developer of Library Management System CBSS has to estimate the reliability of 5 COTS components. After estimating reliability, he/she has to choose which one has the better reliability out of these 5 COTS component. The estimation criteria of these 5 COTS component are as shown in Table II. The values of the criteria are collected from different projects. The graphical representation is also plotted which shows the clear picture of reliability criteria.

Table II. Details of five COTS components based upon estimation criteria

Criteria	*C1*	*C2*	*C3*	*C4*	*C5*
CUR	0.85	0.83	0.81	0.83	0.81
CR	0.77	0.76	0.65	0.75	0.77
OP	0.70	0.76	0.60	0.6	0.70
AC	0.20	0.25	0.26	0.21	0.20
CD	0.14	0.20	0.10	0.15	0.19

From the above table observations it is clear that for Component Usage Ratio criteria for component C1 is better than C2 and C4. Both of there are better than C3 and C5. So we can say that,
For Component Usage Ratio C1>C2=C4>C3>C5
Similarly, for Component Reusability C1=C5>C2>C4>C3
Operational Profile C2>C1=C5>C3=C4
Application Complexity C3>C2>C4>C1=C5
Component Dependency C2>C5>C4>C1>C3

From Figure 2 we can easily relate the criteria with components. It provides a graphical representation that states which reliability criteria affect most on which COTS components.

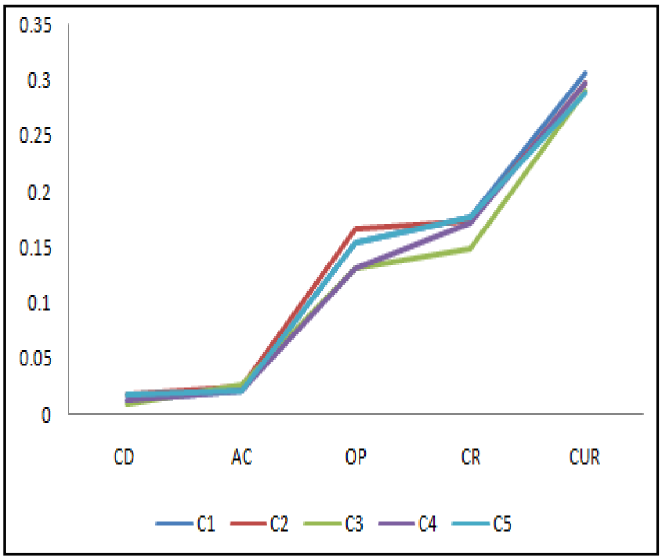

Figure 2: Reliability criteria for COTS components

So it is difficult to estimate the overall reliability of these components and find which component has better reusability. This problem can be solved by HMRE approach. The next step after collecting database is prioritization. Let us consider the developer/integrator of CBSS orders the priority for all these five reliability criteria as: Component Usage Ratio > Component Reusability > Operational Profile

> Application Complexity > Component Dependency. After prioritization a proper weightage can be arbitrarily assign to these five reliability criteria according to the type of application developing. The sum of assigned weighted for all reliability criteria should be equal to 1. i.e,

$$W_{CUR} + W_{CR} + W_{OP} + W_{AC} + W_{CD} = 1$$

Table III. Weight values for each criteria

S.No.	Criteria name	Value of Weights
1	Component Usage Ratio	0.36
2	Component Reusability	0.23
3	Operational Profile	0.22
4	Application Complexity	0.10
5	Component Dependency	0.09

The assigned weighted for each reliability criteria shows the impact of these criteria for estimating the reliability of COTS component. It indicates how many that criterions is important for estimating component reliability. For each component the criteria values are multiplied by its weighted value to determine the weighted score and a metric is formed by using these values. These values are shown in a Table IV. From "Fig. 3" it can be shown that after providing weight to reliability criteria, the functionality of components change.

Table IV. Alternative-Main Criterion-Matrix

	CUR	CR	OP	AC	CD
C1	0.306	0.177	0.154	0.020	0.012
C2	0.298	0.174	0.167	0.025	0.018
C3	0.291	0.149	0.132	0.026	0.009
C4	0.298	0.172	0.132	0.021	0.013
C5	0.288	0.177	0.154	0.020	0.017

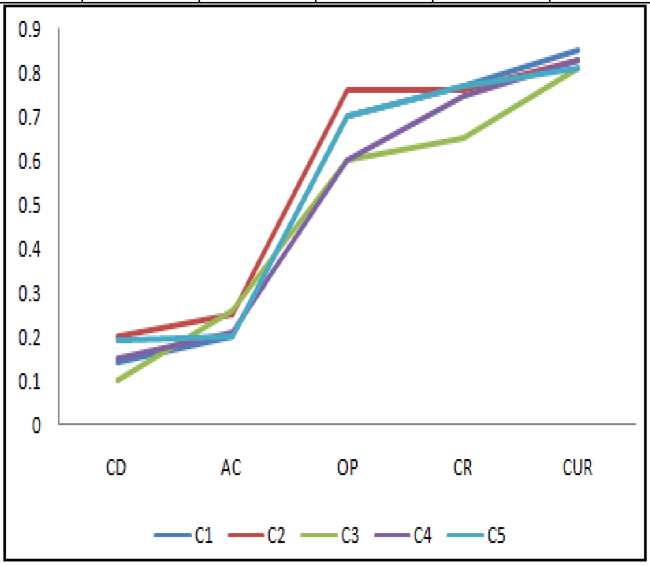

Figure 3: Weighted score of reliability criteria for COTS component

Alternatives Ranking: By using above database reliability of components can be determined by adding each weighted criteria values and rank is ordered to components. It selects the best one among the component.

Table V. Overall reusability score obtained by each COTS component

S. No.	Component Name	Value
1.	C2	0.6838
2.	C1	0.6697
3.	C5	0.6562
4.	C4	0.6378
5.	C3	0.6081

It is shown from Table V that the overall reliability of COTS component C2 is best (0.6838) under these conditions. It also orders rank to the COTS components according to its reliability.

VI. CONCLUSION

This paper proposed Hierarchical Model for Reliability Estimation (HMRE). The estimation of reliability of COTS component is based on five real-time factors that is component usage ratio, operational profile, reusability, application complexity, component dependency. Weighting each reliability criteria and plotting a graphical representation provides a relationship between reliability criteria and components. This approach provides a way to estimate the reliability of COTS component and select the best component among all components on the basis of estimated reliability. This approach orders the rank to each COTS component according to its reliability. From literature review, we can say that these five reliability criteria are the most important criteria for estimating COTS component reliability. The flexibility and accuracy of this framework makes it strong to estimate the reliability of COTS components.

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