VALIDATION OF THE SMBC FRAMEWORK OF SECURITY TESTING USING ANALYTIC HIERARCHY PROCESS

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Abstract. *Software security testing is becoming more challenging in today's concern of changing methodologies. Various types of attacks are still occurring which consequence to serious data breaches. One of the robust frameworks for software security testing is SMBC framework that is being introduced for early stage security testing and assessment during software development. With the use of SMBC framework at early stage of SDLC, security testing and assessment need less effort and cost in comparison to later stages. The principal purpose of this framework is to make secure software at the design phase of SDLC rather to secure the already made software. Under SMBC framework a security metric has been defined called as SMBC metric which is used for security testing and grading. In this paper, it is being tried to show the validation of SMBC Framework through AHP. Pair wise comparison method is used for finding the relative importance of class categories defined in the SMBC framework. Statistical analysis is performed through Chi-square test using MATLAB.*
Keywords: Security testing, Security grading, Security Metric Based on Classes (SMBC), Software Development Life Cycle (SDLC), Analytic Hierarchy Process (AHP)

1. **Introduction.** The various security testing approaches and techniques are presented in the last decade but security sensitive software applications need integrated security measures. One of the best methods to prevent security bugs from appearing in production applications is to focus on the design phase of the SDLC [1]. In today's concern where most of the information is stored and transmitted electronically, data security has become a very prime issue for the society. Hall and Wright analyzed the data breaches between the years 2014 and 2018, and stated that the data security is still complex and challenging [2]. The complexity of the systems and the occurrence of advance technologies are the prime challenges that should be focused and the matter of concern for data security. Hence the more efficient and proper techniques/frameworks are required to be developed to face the challenges of the advance security breaches. A good security framework should consider all the security features and examine the vulnerable areas of the software in a proper manner [3,4]. The characteristics of the object oriented paradigm should go through for the proper security of the software [5,6]. The SMBC framework has been proposed to perform the security testing in an efficient manner and theoretical validation has been performed through Weyuker's properties to show the correctness of the SMBC framework [1]. The SMBC metric is designed to evaluate the level of security. The different values of coefficients for the class categories are used. Finding the correct values of coefficients is a very complex task. There are multiple criteria for deciding the values of these coefficients. Therefore, for the statistical analysis and validation of the SMBC framework, a multiple criteria evaluation approach is recommended called AHP where pair-wise comparison

method is used to find the relative importance of the categories defined in the framework. From this analysis it will be proved with the help of Chi-square test and MATLAB that expected criteria weights and observed criteria weights are equivalent and SMBC framework provides an efficient approach for security testing.

In this research paper the highlights of the SMBC framework will be discussed first to understand the concept behind approach. The validation of the SMBC framework will be shown step by step in detail. For applying the pair-wise comparison method, the relative importance values are found through questionnaire and then the pair-wise matrix is designed. Further the normalized pair-wise matrix is calculated to find the value of consistency ratio. If the value of the consistency ratio lies below the threshold value then only the calculated criteria weights are correct and can be used for further decision making. The analysis of pair-wise comparison and normalized pair-wise comparison is performed with the help of MATLAB. Chi-square test will be applied to proving that there is no significant difference between the calculated values through AHP and the taken values of the SMBC framework. Hence in this way the SMBC framework will be validated.

2. **The SMBC Framework.** Security testing process is a way to evolve software development process in a manner to reduce vulnerabilities. During SDLC, security should be the parallel thought while planning, designing and implementing functionalities in the system. Security testing must be performed in the early phases of SDLC, as in the later phases if any vulnerability is identified then it requires more effort and time to rectify it. The security testing should incorporate the proper designing of the overall system [7,8]. The first two phases of SDLC are the define phase and design phase where all the requirements and basic structures have been made. Attack surface area can be minimized to a great extent at design phase to achieve the secure system. Considering these facts, a security testing framework at design phase of software development life cycle called as SMBC framework has been proposed [1]. A security metric called as SMBC is designed and implemented in the framework for testing the software. SMBC provides the structure for designing any security metric and it is based on categorization of classes in different levels of security. There are four stages in the SMBC framework which should be performed sequentially. The stages are inception stage, preparatory stage, execution stage and assessment stage. At design phase of SDLC, the security requirements and design artifacts will be given as input to the SMBC framework. After the successful realization of all stages, the output from the framework will be a tested design. If the final security grade is satisfactory then forthcoming phases of SDLC will be performed. If the security grade is not satisfactory then rectification in the design will be done to meet the security objectives before proceeding to forthcoming phases of SDLC.

Highlights of SMBC framework are stated as follows:

- The SMBC framework addresses the issue of security testing at design phase of SDLC [9].
- The inception stage of the SMBC framework is performed at requirement phase (also called as define phase) of SDLC [10].
- The preparatory stage, execution stage and assessment stage are performed at design phase of SDLC [1].
- The SMBC framework is based on the categorization of classes according to the weightage in security in object oriented paradigm.
- Application logic (Algorithm/Pseudocode) is used for the category identification of classes.
- The five categories of classes are considered as Highly-Secured, Secured, Moderate-Secured, Less-Secured and Un-Secured.
- The security is best for Highly-Secured classes and then decreasing onwards to the next categories of classes and hence at last the Un-Secured category of classes.

- The following weightage values are considered for each category of classes:
  - Highly-Secured classes (HS) (weightage in security: C1=1)
  - Secured classes (S) (weightage in security: C2 = 0.75)
  - Moderate-Secured classes (MS) (weightage in security: C3 = 0.50)
  - Less-Secured classes (LS) (weightage in security: C4 = 0.25)
  - Un-Secured classes (US) (weightage in security: C5 = 0)
- A security metric called as 'SMBC' is designed for the evaluation of the security level.
- Six security grades are defined as 'O', 'A', 'B', 'C', 'D' and 'E' according to the value of SMBC.
- Security test closure report is prepared according to the resultant security grade.
- SMBC framework has also been implemented as an automated security grading tool called as SMBC tool [11].

3. **Validation of SMBC Framework.** AHP is used for multi-criteria decision making [12]. The AHP is a structured technique for analysis and validation of the decisions that involve multiple criteria, based on mathematics and psychology [13]. It is a tool for dealing with complex decision making and helps to set priorities for taking the best decision. The AHP helps to cover the both subjective and objective aspects of a decision. The AHP is a useful technique for checking the consistency of the decisions, thus reducing the bias in the decision making process. There are basically three steps in AHP [14]. First of all compute the vector of criteria weights, then compute the matrix of scores and at last prioritize the options. Attribute or criteria used in the SMBC framework is class category that can be HS, S, MS, LS or US on which the resultant security grade depends. Therefore, to compute the vector of criteria weights for the SMBC framework the coefficient values of the class categories should be considered. The relative importance of different class categories with respect to the security is determined using the pair-wise comparison method [15,16].

3.1. **Pair-wise comparison.** Pair-wise comparison matrix is created with the help of scale of relative importance. The standard relative importance values are shown in Table 1. Relative importance values called as index values are assigned from 1 to 9. If the criterion P is equally as important as criterion Q, then the index value 1 will be assigned. If the criterion P is too much more important than Q, then the index value 9 will be assigned. The intermediate values can be assigned according to the level of comparative importance. If the comparison is made between the same criteria then the index value 1 will be assigned. Therefore, the diagonal of the matrix will contain value 1. For the reverse relation the reciprocal values will be used. For example, if the index value for [P, Q] is 3 then the index value for [Q, P] will be 1/3. After making all comparisons and assigning index values, change the fractions into decimal values. Now the normalized comparison matrix is created. For it, find the sum of each column and divide the each value of the matrix by the corresponding sum of its column. To calculate the criteria

TABLE 1. Relative importance values

1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Intermediate values
1/3, 1/5, 1/7, 1/9	Values for inverse proportion

weights, the average of each row in the matrix is determined. At last the consistency index and consistency ratio will be calculated.

3.1.1. *Finding the relative importance values for the class categories of SMBC.* The questionnaires have been made for finding the relative importance values for the class categories of SMBC (see Table 2) and given to the software programmers and technical experts. The questions are based on the level of relative importance of the class categories.

TABLE 2. Questionnaire

S	Question	Ans
1	What value do assign for the relative Importance of Highly-Secured class (**HS**) to Secured class (**S**)?	
2	What value do assign for the relative Importance of Highly-Secured class (**HS**) to Moderate-Secured class (**MS**)?	
3	What value do assign for the relative Importance of Highly-Secured class (**HS**) to Less-Secured class (**LS**)?	
4	What value do assign for the relative Importance of Highly-Secured class (**HS**) to Un-Secured class (**US**)?	
5	What value do assign for the relative Importance of Secured class (**S**) to Moderate-Secured class (**MS**)?	
6	What value do assign for the relative Importance of Secured class (**S**) to Less-Secured class (**LS**)?	
7	What value do assign for the relative Importance of Secured class (**S**) to Un-Secured class (**US**)?	
8	What value do assign for the relative Importance of Moderate-Secured class (**MS**) to Less-Secured class (**LS**)?	
9	What value do assign for the relative Importance of Moderate-Secured class (**MS**) to Un-Secured class (**US**)?	
10	What value do assign for the relative Importance of Less-Secured class (**LS**) to Un-Secured class (**US**)?	

Values for relative Importance			
		1	Equal Importance
		3	Moderate Importance
		5	Strong Importance
		7	Very Strong Importance
		9	Extreme Importance
		2, 4, 6, 8	Intermediate Values

TABLE 3. Responses recorded

s.n.	Responses recorded														Avg R-1 to R-14
	R-1	R-2	R-3	R-4	R-5	R-6	R-7	R-8	R-9	R-10	R-11	R-12	R-13	R-14	
1	3	4	4	5	4	5	3	6	4	5	6	4	3	3	4.214286
2	4	5	5	4	6	3	5	5	3	7	5	5	5	5	4.785714
3	9	9	7	7	6	8	8	8	7	7	6	8	8	8	7.571429
4	8	8	7	8	9	9	9	9	9	9	8	9	9	9	8.571429
5	6	6	5	4	4	4	3	5	5	4	4	4	4	4	4.428571
6	6	6	7	6	7	6	7	5	5	6	6	7	5	6	6.071429
7	9	7	8	7	8	7	9	9	9	8	8	8	7	8	8
8	4	4	4	3	4	3	3	3	2	3	3	3	3	3	3.214286
9	8	7	7	6	6	7	6	6	6	7	6	6	6	6	6.428571
10	4	4	3	3	3	4	3	3	3	4	4	4	3	3	3.428571

The questionnaire should be filled by the technical persons who have the knowledge of programming and software security. They can be security experts or the programmers [17,18]. The required inputs are taken from the company "X" (the company name is withheld for the reasons of confidentiality). The responses have been recorded and presented in a tabular form as shown in Table 3. R-1 is response from the person-1, R-2 is response from person-2 and so on.

Now taking the average of each row will give the average value of the relative importance for each required pair of class categories. Rounding the average values will give the final values for the relative importance. The final values are shown in Table 4. These values put in the matrix as shown in Table 5. The values above the forward diagonal are the values according to Table 4 and the values below the forward diagonal are the reciprocal of the corresponding values in the upper half matrix. The AHP calculates a weight for each criterion according to the individual's pair-wise comparisons of the criteria (see Table 5). More value denotes the more importance of the corresponding criteria [17]. Finally it determines global score for each option, and a consequent ranking. The global score can be defined as a weighted sum of the scores with respect to all the criteria. In Table 5 changing the fractional values into decimal values, the updated values are shown in Table 6 and then calculating the sum in each column, the updated values are shown in Table

TABLE 4. Final values for relative importance

s.n.	Relative importance of class categories	Average values received from survey	Rounded values
1	HS to S	4.214286	4
2	HS to MS	4.785714	5
3	HS to LS	7.571429	8
4	HS to US	8.571429	9
5	S to MS	4.428571	4
6	S to LS	6.071429	6
7	S to US	8	8
8	MS to LS	3.214286	3
9	MS to US	6.428571	6
10	LS to US	3.428571	3

TABLE 5. Pair-wise comparison matrix-1

Classes category	HS	S	MS	LS	US
HS	1	4	5	8	9
S	1/4	1	4	6	8
MS	1/5	1/4	1	3	6
LS	1/8	1/6	1/3	1	3
US	1/9	1/8	1/6	1/3	1

TABLE 6. Pair-wise comparison matrix-2

Classes category	HS	S	MS	LS	US
HS	1.00000	4.00000	5.00000	8.00000	9.00000
S	0.25000	1.00000	4.00000	6.00000	8.00000
MS	0.20000	0.25000	1.00000	3.00000	6.00000
LS	0.12500	0.16667	0.33333	1.00000	3.00000
US	0.11111	0.12500	0.16667	0.33333	1.00000

TABLE 7. Pair-wise comparison matrix-3

Classes category	HS	S	MS	LS	US
HS	1.00000	4.00000	5.00000	8.00000	9.00000
S	0.25000	1.00000	4.00000	6.00000	8.00000
MS	0.20000	0.25000	1.00000	3.00000	6.00000
LS	0.12500	0.16667	0.33333	1.00000	3.00000
US	0.11111	0.12500	0.16667	0.33333	1.00000
SUM	1.68611	5.54167	10.50000	18.33333	27.00000

7. Now the normalization of the table should be done to calculate the criteria weights. Normalized pair-wise comparison is shown in next section.

3.1.2. *Graphical analysis of pair-wise comparison.* Graphical analysis has been performed with the help of MATLAB. Graphs are plotted using the plot catalog. Table 7 provides the relative importance values of different class categories (HS, S, MS, LS and US). Using Table 7 the class category graph is plotted on MATLAB (see Figure 1). For each class category, the relative importance of other categories is shown as line graph. The relative importance values of HS class are greater in comparison to other class categories. Therefore, the line graph of HS appears at top in Figure 1. The relative importance values of S class are greater than that of MS class, LS class and US class. Therefore, the line graph of S class appears above the line graph of MS, LS and US. Similarly other line graphs are shown in the figure where the line graph of US appears at the bottom. The relative importance value of each class category with itself is 1; therefore, each line graph passes through the line $y = 1$.
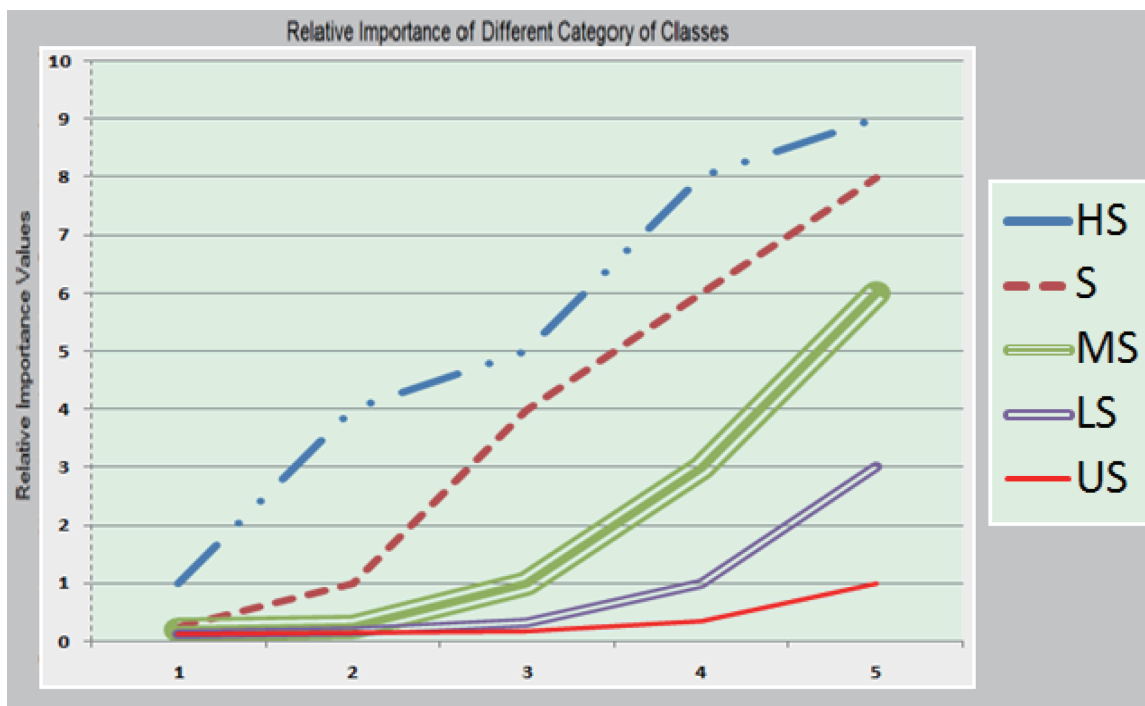

FIGURE 1. Relative importance of different category of classes

3.2. **Normalized pair-wise comparison.** The normalized matrix can be found by dividing the each value by the corresponding sum of the column. Now calculate the criteria weights by taking the average of each row. The normalized comparison matrix is shown in Table 8. After this calculation the original table is again used with the calculated criteria weights as shown in Table 9.

TABLE 8. Normalized comparison matrix

Classes category	HS	S	MS	LS	US	Criteria weights
HS	0.59308	0.72180	0.47619	0.43636	0.33333	0.51215
S	0.14827	0.18045	0.38095	0.32727	0.29630	0.26665
MS	0.11862	0.04511	0.09524	0.16364	0.22222	0.12897
LS	0.07414	0.03008	0.03175	0.05455	0.11111	0.06032
US	0.06590	0.02256	0.01587	0.01818	0.03704	0.03191
SUM	1.68611	5.54167	10.50000	18.33333	27.00000	

TABLE 9. Pair-wise comparison matrix-4

Classes category	HS	S	MS	LS	US
HS	1.00000	4.00000	5.00000	8.00000	9.00000
S	0.25000	1.00000	4.00000	6.00000	8.00000
MS	0.20000	0.25000	1.00000	3.00000	6.00000
LS	0.12500	0.16667	0.33333	1.00000	3.00000
US	0.11111	0.12500	0.16667	0.33333	1.00000
SUM	1.68611	5.54167	10.50000	18.33333	27.00000
Criteria weights	0.51215	0.26665	0.12897	0.06032	0.03191

3.2.1. *Graphical analysis of normalized pair-wise comparison.* Criteria weights are plotted against the category of classes using plot data option of variable editor in MATLAB. In MATLAB editor steps can be written to create a graph as per user needs. Using Table 9, the graph of criteria weights versus category of classes are plotted (see Figure 2). It can be seen from the graph that for the Highly-Secured class, criteria weight is highest and the values of criteria weights decrease towards the lower level of security. Hence the value of criteria weight for the Un-Secured class is least.
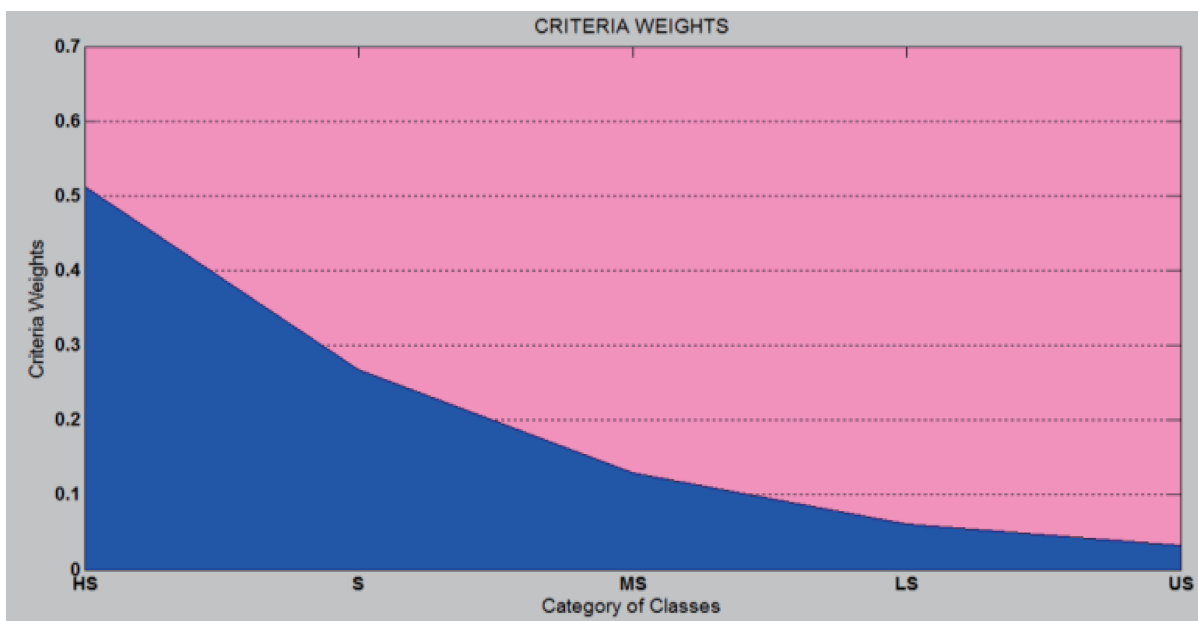

FIGURE 2. Criteria weights versus category of classes

3.2.2. *Calculation of lambda max and consistency ratio.* Pair-wise comparison matrix (see Table 9) is updated to find the value of consistency ratio. Criteria weight multiplied by original values will give the new values for each cell (see Table 10). Weighted sum values are the sum of values in each row. Now calculate the value of weighted sum value divided by corresponding criteria weights in each row. To calculate the $\lambda_{\max}$, the last column of the AHP matrix is used. Taking the average of the values of this last column will give the value of $\lambda_{\max}$ (see Table 11).

TABLE 10. AHP matrix

Classes category	HS	S	MS	LS	US	Weighted sum value	Criteria weights	Weighted sum value/criteria weight
HS	0.51215	1.06659	0.64483	0.48258	0.28718	2.99334	**0.51215**	5.844599
S	0.12804	0.26665	0.51586	0.36194	0.25527	1.52776	**0.26665**	5.729478
MS	0.10243	0.06666	0.12897	0.18097	0.19146	0.67048	**0.12897**	5.198935
LS	0.06402	0.04444	0.04299	0.06032	0.09573	0.30750	**0.06032**	5.097583
US	0.05691	0.03333	0.02149	0.02011	0.03191	0.16375	**0.03191**	5.131684
Criteria weights	0.51215	0.26665	0.12897	0.06032	0.03191			

TABLE 11. Lambda matrix

	Weighted sum value/criteria weight
	5.84459908
	5.7294778
	5.19893461
	5.09758347
	5.13168428
Lambda Max =	5.40045585

Now calculate the consistency index by using following formula:

$$\text{Consistency Index} = (\text{Lambda Max} - n)/(n - 1)$$

Here n is the number of attributes or criteria considered. Here the value of n is 5. Therefore,

$$\text{Consistency Index} = (5.40045585 - 5)/(5 - 1) = 0.100113962$$

Now calculate the consistency ratio by using following formula:

$$\text{Consistency Ratio} = \text{Consistency Index}/\text{Random Index}$$

The value of random index is 1.12 for $n = 5$ (taken from standard table). Therefore,

$$\text{Consistency Ratio} = 0.100113962/1.12 = 0.089387$$

The standard value or threshold value for consistency ratio is 0.10 [14]. It can be seen that value of the consistency ratio is below the threshold value.

Consistency Ratio = 0.089387 < 0.10

Hence the calculated criteria weights can be used for further decision making.

3.3. **Hypothesis testing using Chi-square test.** Chi-square test can be applied to proving that there is no significant difference between the calculated values and the taken values [19,20]. For performing the Chi-square test the following hypothesis has been set.

Null Hypothesis (H_0): There is no significant difference between the calculated values and the taken values of the coefficients for the weightage of different classes in the SMBC framework.

$$C_{i(calculated)} = C_{i(taken)}$$

Alternate Hypothesis (H_1): There is significant difference between the calculated values and the taken values of the coefficients for the weightage of different classes in the SMBC framework.

$$C_{i(calculated)} \neq C_{i(taken)}$$

The Chi-square test calculation is shown in Table 12. Criteria weights calculated through AHP are considered as Expected values (E) and the criteria weights taken in the SMBC framework are shown considered as observed values (O). Calculate the difference between the expected values and observed values and take square of each value. Divide this value by corresponding expected values in each row. Now, taking the sum of the values of this final column will give the final value. Hence, calculate value of Chi = 2.408330863.

TABLE 12. Chi-square test

Criteria weights calculated through AHP (E)	Criteria weights taken in the SMBC framework (O)	O-E	Square(O-E)	Square(O-E)/E
0.51215	1	0.48785	0.237993196	0.464690205
0.26665	0.75	0.48335	0.233628631	0.876166916
0.12897	0.5	0.37103	0.137666881	1.067473742
0.06032	0.25	0.18968	0.035977525	0.596418925
0.03191	0	0.03191	0.001018199	0.031909224

For comparing this calculated value with the threshold value, first find the degree of freedom. Here, degree of freedom $= n - 1 = 5 - 1 = 4$. Now, considering the 5% level of significance find the standard value of Chi from the critical values of Chi table.

Standard value of Chi at 4 degrees of freedom and at 5% level of significance is $= 9.488$.

$$2.408330863 < 9.488$$

Hence the Null hypothesis is accepted at 5% level of significance and alternate hypothesis is rejected strongly. Therefore, fit is good and values taken are correct. The graphical presentation of comparison of expected and observed values is performed through MATLAB as shown in Figure 3. From the graph it can be seen that expected criteria weights and observed criteria weights are similar and equivalent. This implies that the coefficient values of class categories in the SMBC framework are valid and weightage in security for each category of class can be used for the SMBC calculation. Hence the framework is validated.

4. **Results and Conclusion.** Validation of the SMBC framework has been performed through AHP and Chi-square test. For finding the relative importance values for the class categories of SMBC, the questionnaires have been made. Pair wise comparison method is used for finding the relative importance of class categories defined in the SMBC framework. With AHP, the weight for each criterion according to the individual's pairwise comparisons of the criteria has been calculated. Hence, the coefficient values of the class categories have been calculated using AHP. Chi-square test is used to show that there is no significant difference between the calculated values by AHP and the taken values of the coefficients for the weightage of different classes in the SMBC framework. The Null hypothesis is accepted at 5% level of significance and alternate hypothesis is rejected strongly. This implies that weightage of each class category taken in the framework is
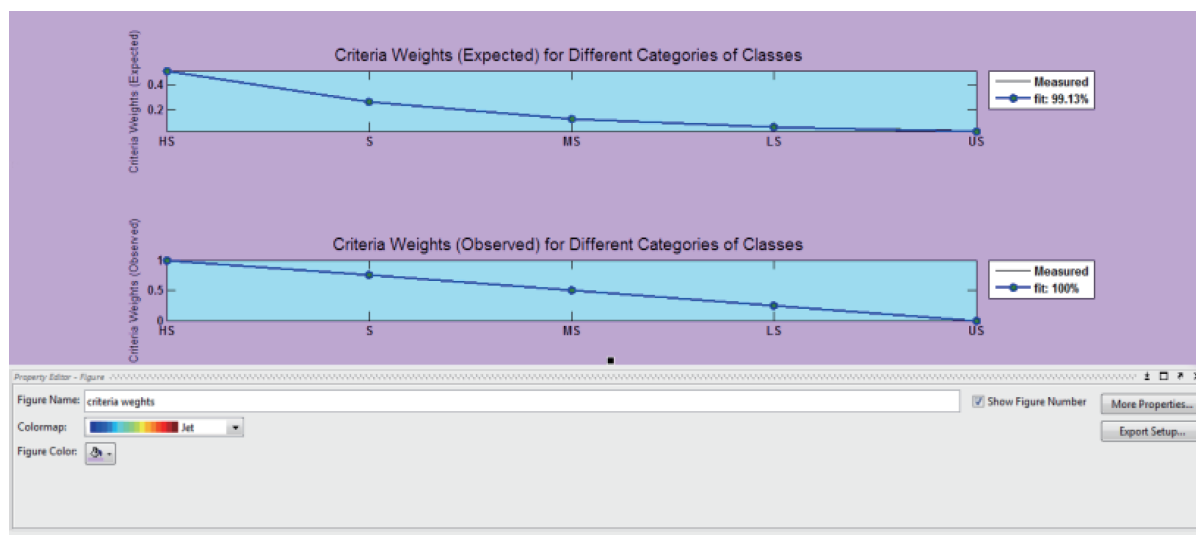
FIGURE 3. Screenshot on MATLAB for criteria weights expected versus observed

valid. Therefore, fit is good and values taken are correct. Data is imported from Excel to MATLAB and plotted against the required dimensions and analyzed. From the analysis it can be seen that expected criteria weights and observed criteria weights are similar and equivalent. Hence, the SMBC framework has been validated through AHP using Chisquare test and MATLAB. The SMBC framework is the security testing and assessment framework for the application software and algorithm is used for testing the security of the software. In future, other artifacts can also be added to make a more robust framework. The SMBC framework is for the security testing of application software. In future, framework can be extended to include the testing of other components of the system also.

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