CHAPTER 5

EMPIRICAL VALIDATION AND PREDICTIVE ACCURACY OF THE MODEL

5.1 BACKGROUND

Validations are generally categorized as theoretical and empirical. Theoretical validation addresses the question ‘is the model measuring the attribute it is purporting to measure?’, and empirical validation addresses the question ‘is the model useful in the sense that it is related to other variables in expected ways?’(Vliet, 2008). In other words theoretical validation allows the researcher to conclude that the relationships involved in the model are valid in the light of theoretical concepts. While the empirical validation assesses how well the model is able to estimate or quantify the respective quality attributes (Chrissis, et. al, 2006).

Along with validating a model ensuring its predictive accuracy is one of the important aspects of any model being proposed. Accurate modeling can assists in scheduling resources and evaluating risk factors. Any improvement in the accuracy of reliability prediction can significantly impact the quality of the developing software application (Walkerden and Jeffery, 1999). It is evident from the literature that researchers have been using various measures to ensure the predictive accuracy of the developed models. The most popular measures include Magnitude of Relative Error (MRE), Mean Magnitude of Relative Error (MMRE), Median Magnitude of Relative Error (MdMRE) and Prediction at level n (Pred(n)). Most of these measures are based on two terms, the actual and the predicted values (Conte et al., 1986).

This chapter assesses how effectively the reliability model (ESRPM) developed in the previous chapter is able to predict the reliability of the developing software at its design stage. In order to ensure or validate the quantifying ability of the model the researcher has contacted the well established and reputed software developing organizations at Noida and Lucknow and subsequently collected the relevant data for requirements and design stage of 20 software projects, those had already been implemented and currently in operation. The data set is shown in figure 5.1. In order to validate the model comprehensively the researcher has performed both theoretical as well as empirical validations in the following sections of this chapter.

5.2 THEORITICAL VALIDATION

Theoretical validation of the developed model provides the supporting evidence as to whether a model really captures the relationships that it should have. In order words theoretical validation allows the researcher to conclude that the relationships involved in the model are valid in the light of theoretical concepts. The main goal of theoretical validation is to assess whether a developed model actually measures what it purports to measure (Mustafa and Khan, 2005). Such validation of a model establishes its construct validity i.e. it proves that they are valid measures for the constructs that are used as variables in the study.

Project	RS	RIW	RC	RFD	RLR	EM	CoM	IM	CM	DLR
1	H	H	L	L	VH	H	H	L	L	VH
2	H	H	M	L	VH	H	H	M	L	VH
3	H	H	L	M	VH	H	H	L	M	VH
4	M	H	L	M	H	M	H	M	H	H
5	H	M	M	L	H	H	M	M	L	H
6	H	H	M	M	H	H	H	M	H	M
7	M	H	L	M	H	M	H	L	H	H
8	M	M	M	M	M	M	M	M	M	M
9	M	M	M	L	M	M	M	M	L	M
10	M	L	L	M	M	M	H	M	L	H
11	M	M	L	L	M	M	M	H	L	M
12	L	M	L	M	M	L	H	M	M	M
13	L	M	M	M	M	L	M	M	M	M
14	M	M	L	M	M	M	H	L	M	H
15	L	M	M	M	M	M	H	L	L	M
16	M	M	H	M	L	M	M	H	M	L
17	L	L	M	H	L	H	L	H	L	L
18	M	M	H	H	VL	M	M	H	H	L
19	L	L	H	H	VL	L	H	H	H	VL
20	L	M	H	H	VL	H	M	H	H	VL

Figure 5.1 Data Set

5.3 SENSITIVITY ANALYSIS

In order to justify the effect of software metrics in the proposed model, sensitivity analysis is preformed. In the sensitivity analysis, the impact of input variable on output variable is analyzed. It is desirable to know the significance of input metrics on the prediction of software reliability. As explained in the previous chapter that the Design Level Reliability (DLR) has been computed in terms of Requirements Level Reliability (RLR), along with four other OOD metrics (IM, EM, CM, CoM). While, the value of RLR depends on four requirements stage metrics RS, RIW, RC and RFD. Therefore, it seems important to determine the impact of a particular software metrics on the software reliability. Once the impact of the particular software metrics on reliability has been identified, the better and more cost effectively it can be controlled to improve the overall reliability and quality of the product. The following sections comprehensively elaborate on this issue.

5.3.1 Sensitivity of RLR with respect to change in RFD

Looking at the values of the following table 5.1 and the figure 5.2, it can be easily noticed that for any constant value of RS, RIW and RC, the metric RFD has a negative impact on the RLR. When the value of RFD increases, it forces the RLR to decrease. In other words, Reliability of the software will decrease as the density of faults in the SRS increases.

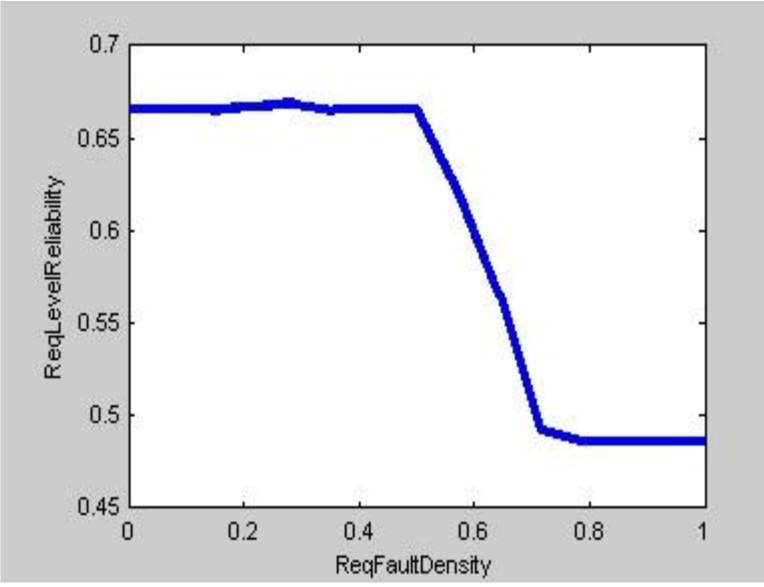


Figure 5.2 Sensitivity of RLR with respect to Requirements Fault Density

Table 5.1 Sensitivity of RLR with respect to Requirements Fault Density

RS = 0%		RS = 25%		RS = 50%		RS = 75%		RS = 100%	
RIW = 0%		RIW = 25%		RIW = 50%		RIW = 75%		RIW = 100%	
RC = 0%		RC = 25%		RC = 50%		RC = 75%		RC = 100%	
RFD	RLR	RFD	RLR	RFD	RLR	RFD	RLR	RFD	RLR
0.0	0.633	0.0	0.544	0.0	0.665	0.0	0.800	0.0	0.800
0.2	0.639	0.2	0.544	0.2	0.665	0.2	0.800	0.2	0.800
0.4	0.633	0.4	0.544	0.4	0.665	0.4	0.641	0.4	0.633
0.6	0.569	0.6	0.427	0.6	0.602	0.6	0.642	0.6	0.642
0.8	0.400	0.8	0.263	0.8	0.486	0.8	0.641	0.8	0.637
1.0	0.400	1.0	0.263	1.0	0.486	1.0	0.641	1.0	0.633

5.3.2 Sensitivity of RLR with respect to change in RC

Looking at the values of the following table 5.2 and the figure 5.3, it can be easily noticed that for any constant value of RS, RIW and RFD, the metric RC has a negative impact on the RLR. When the value of RC increases, it forces the RLR to decrease. In other words, Reliability of the software will decrease as the functionalities get complicated in the SRS.

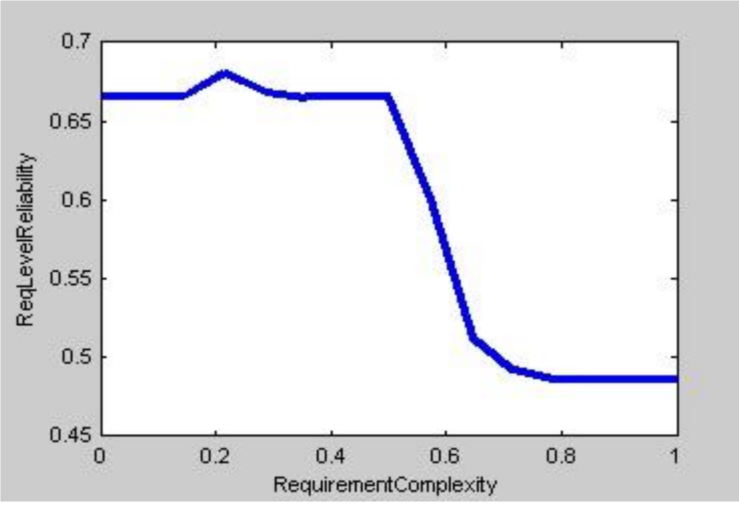


Figure 5.3 Sensitivity of RLR with respect to Requirements Complexity

Table 5.2 Sensitivity of RLR with respect to Requirements Complexity

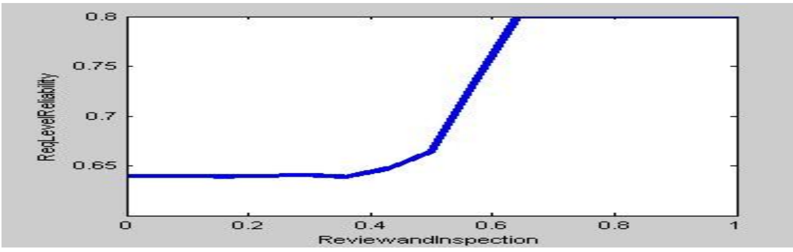
RS = 0%		RS = 25%		RS = 50%		RS = 75%		RS = 100%	
RIW = 0%		RIW = 25%		RIW = 50%		RIW = 75%		RIW = 100%	
RFD = 0%		RFD = 25%		RFD = 50%		RFD = 75%		RFD = 100%	
RC	RLR	RC	RLR	RC	RLR	RC	RLR	RC	RLR
0.0	0.633	0.0	0.551	0.0	0.665	0.0	0.800	0.0	0.800
0.2	0.642	0.2	0.551	0.2	0.676	0.2	0.800	0.2	0.800
0.4	0.633	0.4	0.551	0.4	0.665	0.4	0.641	0.4	0.633
0.6	0.400	0.6	0.265	0.6	0.534	0.6	0.645	0.6	0.645
0.8	0.400	0.8	0.271	0.8	0.486	0.8	0.641	0.8	0.637
1.0	0.400	1.0	0.271	1.0	0.486	1.0	0.641	1.0	0.633

5.3.3 Sensitivity of RLR with respect to change in RIW

Looking at the values of the following table 5.3 and the figure 5.4, it can be easily noticed that for any constant value of RS, RFD and RC, the metric RIW has a positive impact on the RLR. When the value of RIW increases, it forces the RLR to increase also. In other words, the developing software will be more reliable if the SRS has reviewed and inspected more.

Table 5.3 Sensitivity of RLR with respect to Review Inspection and Walkthrough

RS = 0%		RS = 25%		RS = 50%		RS = 75%		RS = 100%	
RFD = 0%		RFD = 25%		RFD = 50%		RFD = 75%		RFD = 100%	
RC = 0%		RC = 25%		RC = 50%		RC = 75%		RC = 100%	
RIW	RLR	RIW	RLR	RIW	RLR	RIW	RLR	RIW	RLR
0.0	0.633	0.0	0.544	0.0	0.639	0.0	0.400	0.0	0.400
0.2	0.639	0.2	0.544	0.2	0.639	0.2	0.400	0.2	0.400
0.4	0.633	0.4	0.544	0.4	0.639	0.4	0.641	0.4	0.633
0.6	0.800	0.6	0.700	0.6	0.800	0.6	0.642	0.6	0.642
0.8	0.800	0.8	0.700	0.8	0.800	0.8	0.641	0.8	0.636
1.0	0.800	1.0	0.700	1.0	0.800	1.0	0.641	1.0	0.633



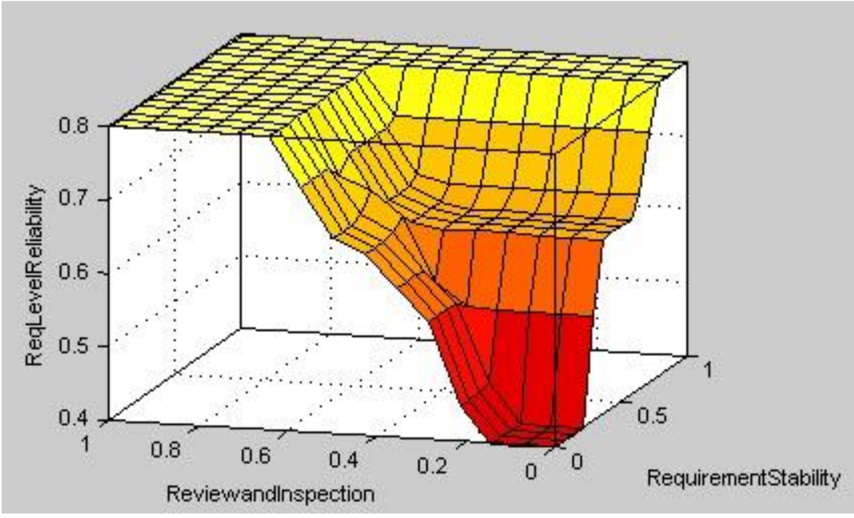


Figure 5.4 Sensitivity of RLR with respect to Review Inspection and Walkthrough

5.3.4 Sensitivity of RLR with respect to change in RS

Looking at the values of the following table 5.4 and the figure 5.5, 5.6, it can be easily noticed that for any constant value of RIW, RFD and RC, the metric RS has a positive impact on the RLR. When the value of RS increases, it forces the RLR to increase also. In other words, the developing software will be more reliable if the requirements have stability, i.e. frequency of change request is as low as possible.

Table 5.4 Sensitivity of RLR with respect to Requirements Stability

RFD = 0%		RFD = 25%		RFD = 50%		RFD = 75%		RFD = 100%	
RIW = 0%		RIW = 25%		RIW = 50%		RIW = 75%		RIW = 100%	
RC = 0%		RC = 25%		RC = 50%		RC = 75%		RC = 100%	
RS	RLR	RS	RLR	RS	RLR	RS	RLR	RS	RLR
0.0	0.633	0.0	0.544	0.0	0.665	0.0	0.400	0.0	0.400
0.2	0.640	0.2	0.544	0.2	0.669	0.2	0.400	0.2	0.400
0.4	0.635	0.4	0.583	0.4	0.665	0.4	0.639	0.4	0.635
0.6	0.639	0.6	0.583	0.6	0.665	0.6	0.639	0.6	0.639
0.8	0.800	0.8	0.724	0.8	0.800	0.8	0.639	0.8	0.639
1.0	0.800	1.0	0.724	1.0	0.800	1.0	0.639	1.0	0.633

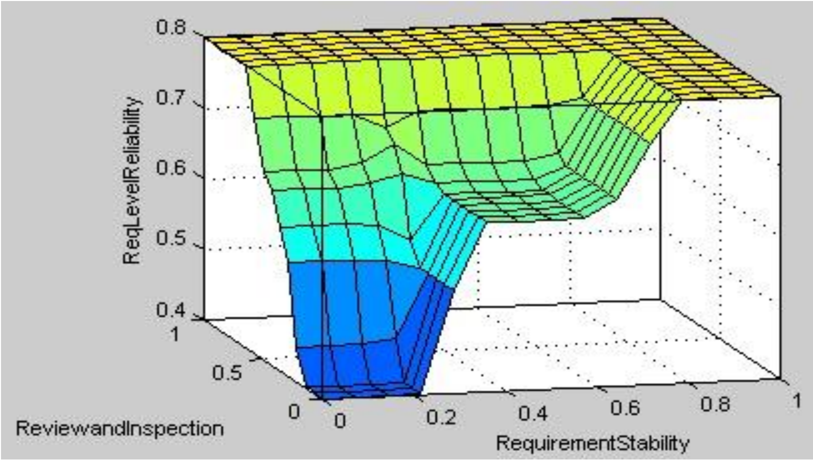


Figure 5.5 Sensitivity of RLR with respect to Requirements Stability

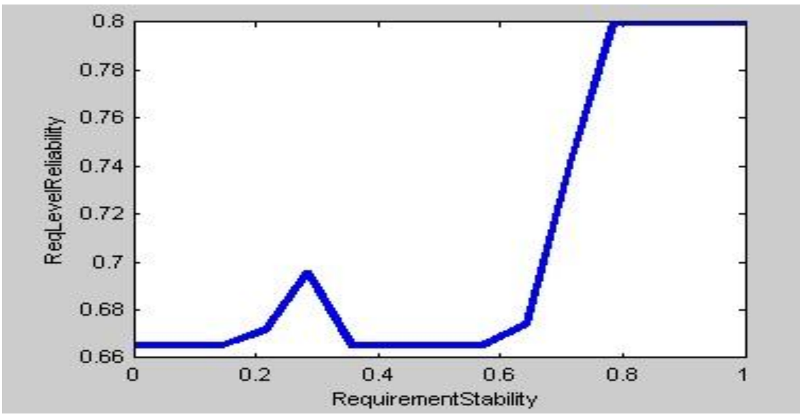


Figure 5.6 Sensitivity of RLR with respect to Requirements Stability

5.3.5 Sensitivity of RLR with respect to change in RS & RIW

Looking at the values of the following table 5.5 and the figure 5.7, it can be easily noticed that for any constant value of RFD and RC, both the metric RS and RIW has a positive impact on the RLR. When the values of RS and RIW increase, it forces the RLR to increase also. In other words, the developing software will be more reliable if the requirements have higher level of stability, along with the more review and inspections.

Table 5.5 Sensitivity of RLR with respect to RIW and Requirements Stability

RFD = 0%		RFD = 25%		RFD = 50%		RFD = 75%		RFD = 100%	
RC = 0%		RC = 25%		RC = 50%		RC = 75%		RC = 100%	
RS, RIW	RLR	RS, RIW	RLR	RS, RIW	RLR	RS, RIW	RLR	RS, RIW	RLR
0.0	0.633	0.0	0.544	0.0	0.400	0.0	0.133	0.0	0.113
0.2	0.640	0.2	0.544	0.2	0.400	0.2	0.138	0.2	0.138
0.4	0.800	0.4	0.685	0.4	0.639	0.4	0.400	0.4	0.400
0.6	0.939	0.6	0.825	0.6	0.800	0.6	0.642	0.6	0.642
0.8	0.944	0.8	0.837	0.8	0.800	0.8	0.639	0.8	0.639
1.0	0.953	1.0	0.837	1.0	0.800	1.0	0.639	1.0	0.633

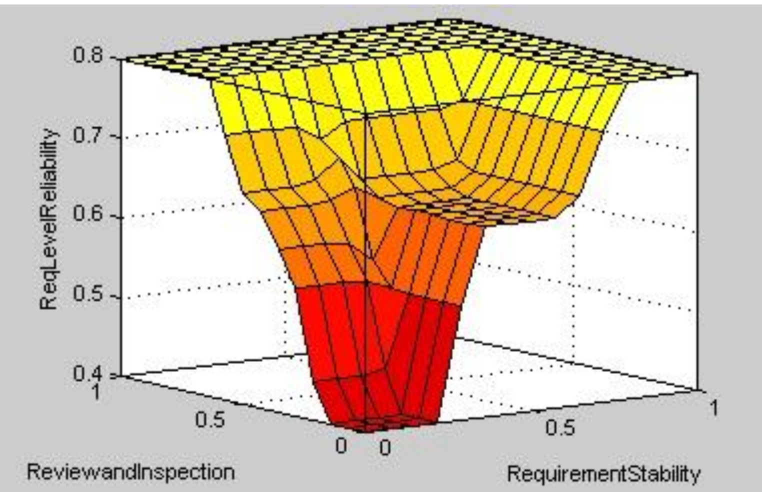


Figure 5.7 Sensitivity of RLR with respect to RIW and Requirements Stability

5.3.6 Sensitivity of RLR with respect to change in RC & RFD

Looking at the values of the following table 5.6 and the figure 5.8, it can be easily noticed that for any constant value of RS and RIW, the metric values of RC and RFD has a negative impact on the RLR. When the value of RC and RFD increases, it forces the RLR to decrease. In other words, Reliability of the software will decrease as the functionalities get more complicated in the SRS along with the fault density.

Table 5.6 Sensitivity of RLR with respect to RFD and Requirement Complexity

RS = 0%		RS = 25%		RS = 50%		RS = 75%		RS = 100%	
RIW = 0%		RIW = 25%		RIW = 50%		RIW = 75%		RIW = 100%	
RC, RFD	RLR	RC, RFD	RLR	RC, RFD	RLR	RC, RFD	RLR	RC, RFD	RLR
0.0	0.633	0.0	0.643	0.0	0.816	0.0	0.941	0.0	0.953
0.2	0.642	0.2	0.643	0.2	0.820	0.2	0.939	0.2	0.939
0.4	0.400	0.4	0.536	0.4	0.665	0.4	0.800	0.4	0.800
0.6	0.156	0.6	0.265	0.6	0.534	0.6	0.645	0.6	0.645
0.8	0.127	0.8	0.149	0.8	0.486	0.8	0.641	0.8	0.637
1.0	0.113	1.0	0.149	1.0	0.486	1.0	0.641	1.0	0.633

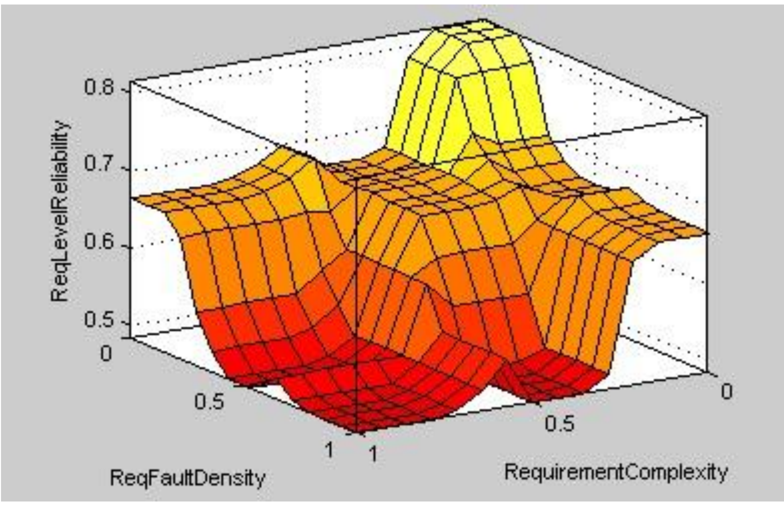


Figure 5.8 Sensitivity of RLR with respect to RFD and Requirement Complexity

5.3.7 Sensitivity of RLR with respect to change in RS & RC

Looking at the values of the following table 5.7 and the figure 5.9, it can be easily noticed that for any constant value of RFD and RIW, the metric values of RC and RS has neither positive nor negative impact on the RLR. In other words, Reliability of the software will neither decrease nor increase when both RS and RC increases simultaneously.

Table 5.7 Sensitivity of RLR with respect to Requirement Stability and Complexity

RFD = 0%		RFD = 25%		RFD = 50%		RFD = 75%		RFD = 100%	
RIW = 0%		RIW = 25%		RIW = 50%		RIW = 75%		RIW = 100%	
RS, RC	RLR	RS, RC	RLR	RS, RC	RLR	RS, RC	RLR	RS, RC	RLR
0.0	0.633	0.0	0.562	0.0	0.486	0.0	0.639	0.0	0.633
0.2	0.642	0.2	0.557	0.2	0.504	0.2	0.642	0.2	0.642
0.4	0.400	0.4	0.521	0.4	0.665	0.4	0.639	0.4	0.635
0.6	0.400	0.6	0.545	0.6	0.534	0.6	0.645	0.6	0.645
0.8	0.639	0.8	0.685	0.8	0.639	0.8	0.639	0.8	0.639
1.0	0.633	1.0	0.685	1.0	0.639	1.0	0.639	1.0	0.633

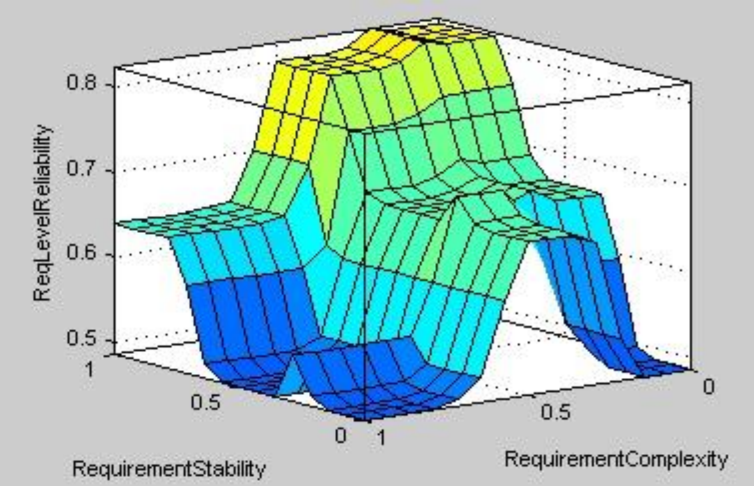


Figure 5.9 Sensitivity of RLR with respect to Requirement Stability and Complexity

5.3.8 Sensitivity of RLR with respect to change in RS & RFD

Looking at the values of the following table 5.8 and the figure 5.10, it can be easily noticed that for any constant value of RC and RIW, the metric values of RFD and RS has neither positive nor negative impact on the RLR. In other words, Reliability of the software will neither decrease nor increase when both RS and RFD increases simultaneously.

Table 5.8 Sensitivity of RLR with respect to Requirements Stability and RFD

RIW = 0%		RIW = 25%		RIW = 50%		RIW = 75%		RIW = 100%	
RC = 0%		RC = 25%		RC = 50%		RC = 75%		RC = 100%	
RS, RFD	RLR	RS, RFD	RLR	RS, RFD	RLR	RS, RFD	RLR	RS, RFD	RLR
0.0	0.633	0.0	0.544	0.0	0.486	0.0	0.639	0.0	0.633
0.2	0.640	0.2	0.544	0.2	0.492	0.2	0.640	0.2	0.640
0.4	0.400	0.4	0.566	0.4	0.665	0.4	0.639	0.4	0.635
0.6	0.400	0.6	0.556	0.6	0.602	0.6	0.642	0.6	0.642
0.8	0.639	0.8	0.685	0.8	0.639	0.8	0.639	0.8	0.639
1.0	0.633	1.0	0.685	1.0	0.639	1.0	0.639	1.0	0.633

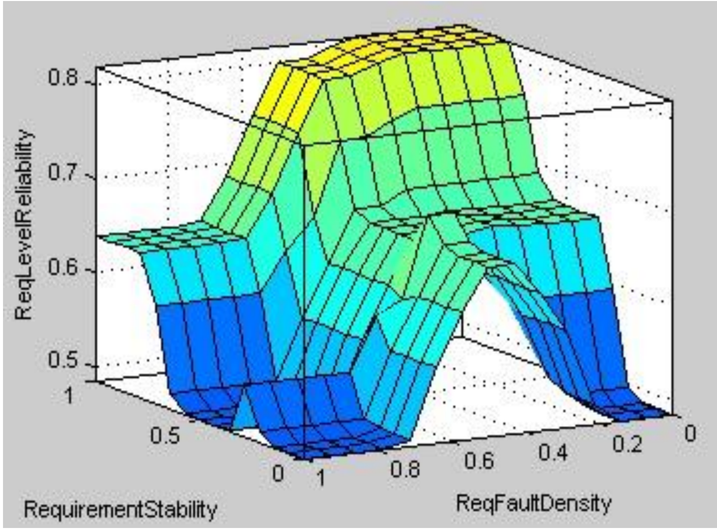


Figure 5.10 Sensitivity of RLR with respect to Requirements Stability and RFD

5.3.9 Sensitivity of RLR with respect to change in RC & RIW

Looking at the values of the following table 5.9 and the figure 5.11, it can be easily noticed that for any constant value of RFD and RS, the metric values of RC and RIW has neither positive nor negative impact on the RLR. In other words, Reliability of the software will neither decrease nor increase both RIW and RC increases simultaneously.

Table 5.9 Sensitivity of RLR with respect to RIW and Requirements Complexity

RFD = 0%		RFD = 25%		RFD = 50%		RFD = 75%		RFD = 100%	
RS = 0%		RS = 25%		RS = 50%		RS = 75%		RS = 100%	
RC, RIW	RLR	RC, RIW	RLR	RC, RIW	RLR	RC, RIW	RLR	RC, RIW	RLR
0.0	0.633	0.0	0.643	0.0	0.400	0.0	0.641	0.0	0.633
0.2	0.642	0.2	0.643	0.2	0.400	0.2	0.642	0.2	0.642
0.4	0.400	0.4	0.536	0.4	0.636	0.4	0.641	0.4	0.633
0.6	0.645	0.6	0.645	0.6	0.645	0.6	0.645	0.6	0.645
0.8	0.637	0.8	0.643	0.8	0.637	0.8	0.641	0.8	0.637
1.0	0.633	1.0	0.643	1.0	0.636	1.0	0.641	1.0	0.633

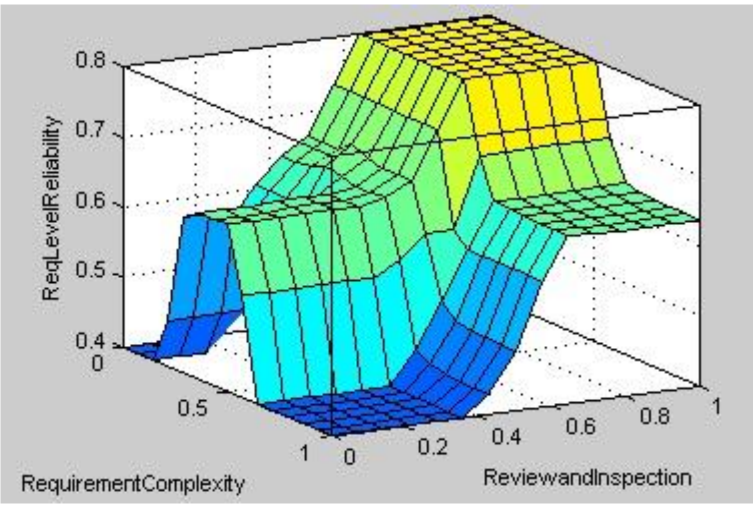


Figure 5.11 Sensitivity of RLR with respect to RIW and Requirements Complexity

5.3.10 Sensitivity of RLR with respect to change in RIW & RFD

Looking at the values of the following table 5.10 and the figure 5.12, it can be easily noticed that for any constant value of RS and RC, the metric values of RIW and RFD has neither positive nor negative impact on the RLR. In other words, Reliability of the software will neither decrease nor increase both RIW and RFD increases simultaneously.

Table 5.10 Sensitivity of RLR with respect to RIW and RFD

RS = 0%		RS = 25%		RS = 50%		RS = 75%		RS = 100%	
RC = 0%		RC = 25%		RC = 50%		RC = 75%		RC = 100%	
RIW, RFD	RLR	RIW, RFD	RLR	RIW, RFD	RLR	RIW, RFD	RLR	RIW, RFD	RLR
0.0	0.633	0.0	0.644	0.0	0.400	0.0	0.641	0.0	0.633
0.2	0.639	0.2	0.644	0.2	0.400	0.2	0.641	0.2	0.639
0.4	0.400	0.4	0.566	0.4	0.639	0.4	0.641	0.4	0.633
0.6	0.642	0.6	0.711	0.6	0.724	0.6	0.642	0.6	0.642
0.8	0.637	0.8	0.644	0.8	0.639	0.8	0.641	0.8	0.637
1.0	0.633	1.0	0.644	1.0	0.639	1.0	0.641	1.0	0.633

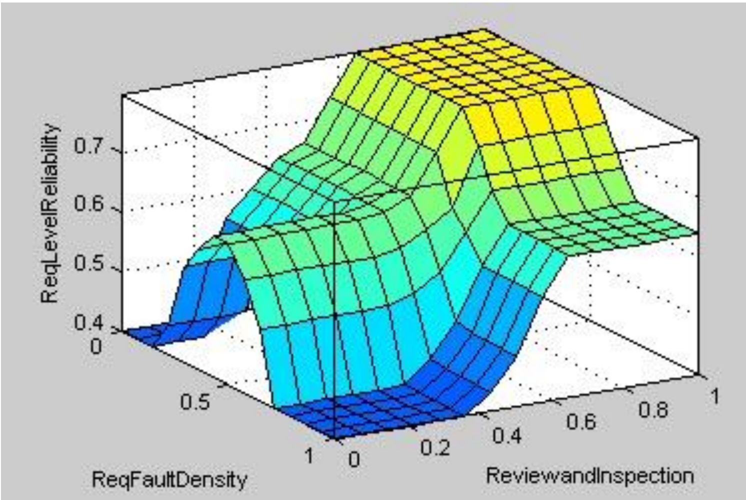


Figure 5.12 Sensitivity of RLR with respect to RIW and RFD

5.3.11 Sensitivity of DLR with respect to change in CoM

Looking at the values of the following table 5.11 and the figure 5.13, it can be easily noticed that for any constant value of IM, EM, CM and RLR, the metric CoM has a positive impact on the DLR. When the value of CoM increases, it forces the DLR to increase also. In other words, the developing software will be more reliable if the design has higher level of Cohesion.

Table 5.11 Sensitivity of DLR with respect to Cohesion

EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
CoM	DLR	CoM	DLR	CoM	DLR	CoM	DLR	CoM	DLR
0.0	0.350	0.0	0.350	0.0	0.450	0.0	0.450	0.0	0.550
0.2	0.350	0.2	0.350	0.2	0.450	0.2	0.450	0.2	0.550
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.550	0.4	0.750
0.6	0.350	0.6	0.350	0.6	0.550	0.6	0.550	0.6	0.750
0.8	0.550	0.8	0.550	0.8	0.650	0.8	0.650	0.8	0.750
1.0	0.550	1.0	0.550	1.0	0.650	1.0	0.650	1.0	0.750

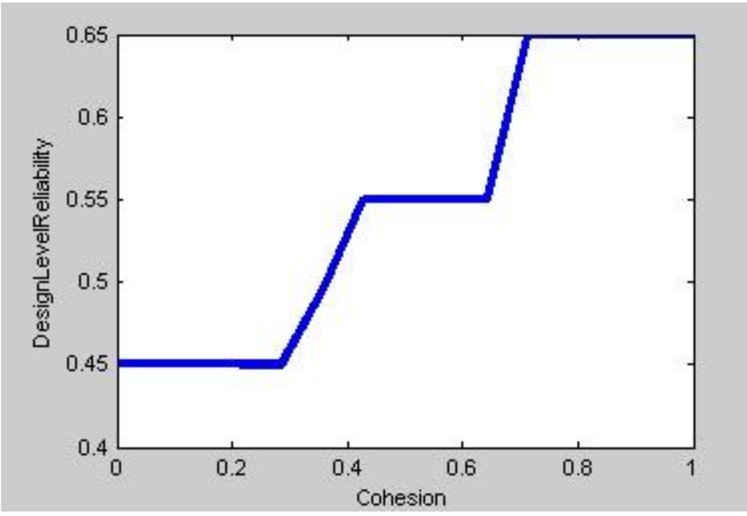


Figure 5.13 Sensitivity of DLR with respect to Cohesion

5.3.12 Sensitivity of DLR with respect to change in EM

Looking at the values of the following table 5.12 and the figure 5.14, it can be easily noticed that for any constant value of IM, CM, CoM and RLR, the metric EM has a positive impact on the DLR. When the value of EM increases, it forces the DLR to increase also. In other words, the developing software will be more reliable if the design has higher level of encapsulation.

Table 5.12 Sensitivity of DLR with respect to Encapsulation

CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
EM	DLR	EM	DLR	EM	DLR	EM	DLR	EM	DLR
0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.450	0.0	0.750
0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.450	0.2	0.750
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.550	0.4	0.750
0.6	0.350	0.6	0.350	0.6	0.550	0.6	0.550	0.6	0.750
0.8	0.550	0.8	0.550	0.8	0.650	0.8	0.650	0.8	0.750
1.0	0.550	1.0	0.550	1.0	0.650	1.0	0.650	1.0	0.750

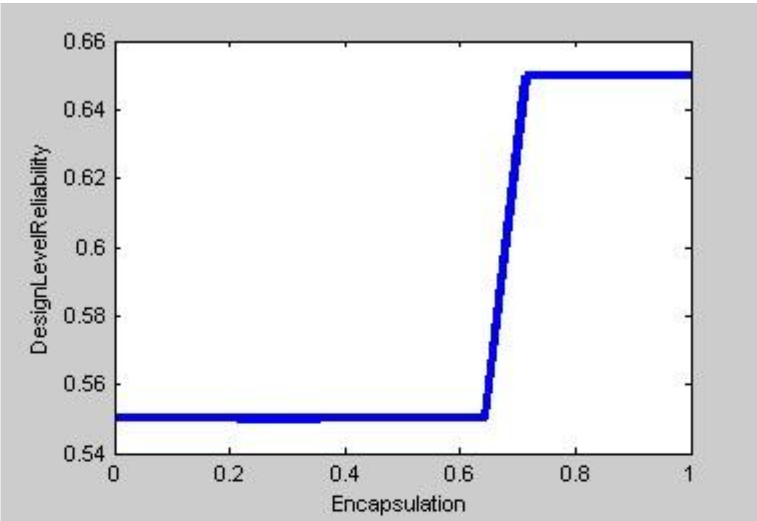


Figure 5.14 Sensitivity of DLR with respect to Encapsulation

5.3.13 Sensitivity of DLR with respect to change in IM

Looking at the values of the following table 5.13 and the figure 5.15, it can be easily noticed that for any constant value of EM, CM, CoM and RLR, the metric IM has a negative impact on the DLR. When the value of IM increases, it forces the DLR to decrease. In other words, Reliability of the software will decrease as the inheritance dominates the object oriented design.

Table 5.13 Sensitivity of DLR with respect to Inheritance

EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
IM	DLR	IM	DLR	IM	DLR	IM	DLR	IM	DLR
0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.750	0.0	0.937
0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.750	0.2	0.925
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.650	0.4	0.925
0.6	0.350	0.6	0.350	0.6	0.550	0.6	0.650	0.6	0.925
0.8	0.114	0.8	0.127	0.8	0.350	0.8	0.650	0.8	0.750
1.0	0.096	1.0	0.127	1.0	0.350	1.0	0.650	1.0	0.750

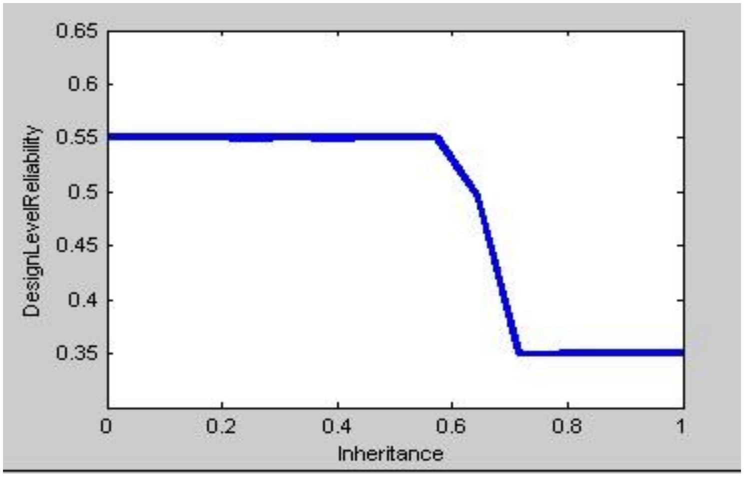


Figure 5.15 Sensitivity of DLR with respect to Inheritance

5.3.14 Sensitivity of DLR with respect to change in CM

Looking at the values of the following table 5.14 and the figure 5.16, it can be easily noticed that for any constant value of EM, IM, CoM and RLR, the metric CM has a negative impact on the DLR. When the value of CM increases, it forces the DLR to decrease. In other words, Reliability of the software will decrease as the coupling increases in the object oriented design.

Table 5.14 Sensitivity of DLR with respect to Coupling

EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
CM	DLR	CM	DLR	CM	DLR	CM	DLR	CM	DLR
0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.650	0.0	0.937
0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.650	0.2	0.925
0.4	0.109	0.4	0.127	0.4	0.550	0.4	0.650	0.4	0.928
0.6	0.114	0.6	0.127	0.6	0.550	0.6	0.650	0.6	0.925
0.8	0.114	0.8	0.127	0.8	0.350	0.8	0.650	0.8	0.750
1.0	0.096	1.0	0.127	1.0	0.350	1.0	0.650	1.0	0.750

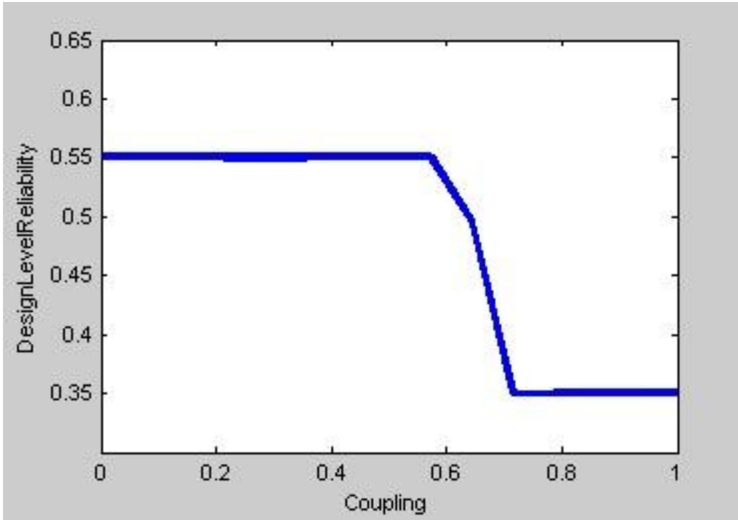


Figure 5.16 Sensitivity of DLR with respect to Coupling

5.3.15 Sensitivity of DLR with respect to change in RLR

Looking at the values of the following table 5.15 and the figure 5.17, it can be easily noticed that for any constant value of IM, EM, CM and CoM, the RLR has a positive impact on the DLR. When the value of RLR increases, it forces the DLR to increase also. In other words, the developing software will be more reliable at the design level if it has higher requirements level reliability.

Table 5.15 Sensitivity of DLR with respect to Requirement Level Reliability

EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
RLR	DLR	RLR	DLR	RLR	DLR	RLR	DLR	RLR	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.550
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.550
0.4	0.550	0.4	0.550	0.4	0.550	0.4	0.550	0.4	0.550
0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550
0.8	0.701	0.8	0.667	0.8	0.550	0.8	0.667	0.8	0.701
1.0	0.937	1.0	0.916	1.0	0.750	1.0	0.750	1.0	0.750

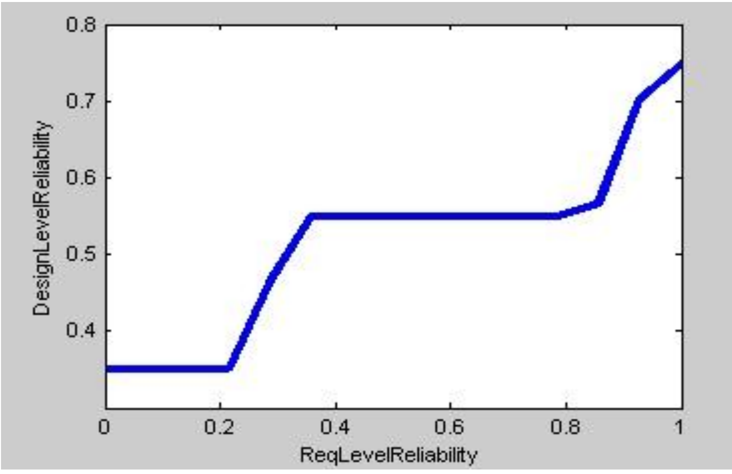


Figure 5.17 Sensitivity of DLR with respect to Requirement Level Reliability

5.3.16 Sensitivity of DLR with respect to change in RLR & EM

Looking at the values of the following table 5.16 and the figure 5.18, it can be easily noticed that for any constant value of IM, CM and CoM, both the metric RLR and EM has a positive impact on the DLR. When the values of RLR and EM increase, it forces the DLR to increase also. In other words, the developing software will be more reliable if it has higher level of requirements level reliability and OOD has higher level of encapsulation.

Table 5.16 Sensitivity of DLR with respect to Req. Level Reliability and Encapsulation

IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
RLR, EM	DLR	RLR, EM	DLR	RLR, EM	DLR	RLR, EM	DLR	RLR, EM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.127	0.0	0.096
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.127	0.2	0.118
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.350	0.4	0.350
0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550
0.8	0.750	0.8	0.750	0.8	0.750	0.8	0.667	0.8	0.683
1.0	0.937	1.0	0.920	1.0	0.937	1.0	0.750	1.0	0.750

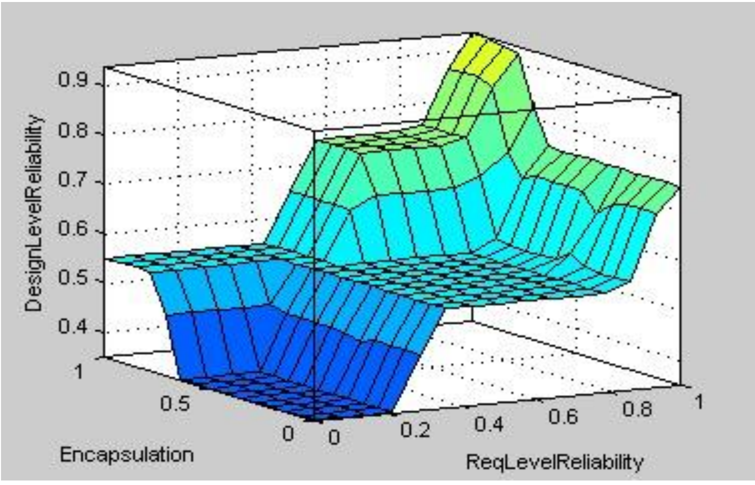


Figure 5.18 Sensitivity of DLR with respect to Req. Level Reliability and Encapsulation

5.3.17 Sensitivity of DLR with respect to change in RLR & CoM

Looking at the values of the following table 5.17 and the figure 5.19, it can be easily noticed that for any constant value of IM, CM and EM, both the metric RLR and CoM has a positive impact on the DLR. When the values of RLR and CoM increase, it forces the DLR to increase also. In other words, the developing software will be more reliable if it has higher level of requirements level reliability along with the OOD with higher level of cohesion.

Table 5.17 Sensitivity of DLR with respect to Req. Level Reliability and Cohesion

IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
RLR, CoM	DLR	RLR, CoM	DLR	RLR, CoM	DLR	RLR, CoM	DLR	RLR, CoM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.127	0.0	0.096
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.127	0.2	0.118
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.550	0.4	0.550
0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550
0.8	0.846	0.8	0.827	0.8	0.750	0.8	0.667	0.8	0.683
1.0	0.937	1.0	0.916	1.0	0.935	1.0	0.750	1.0	0.750

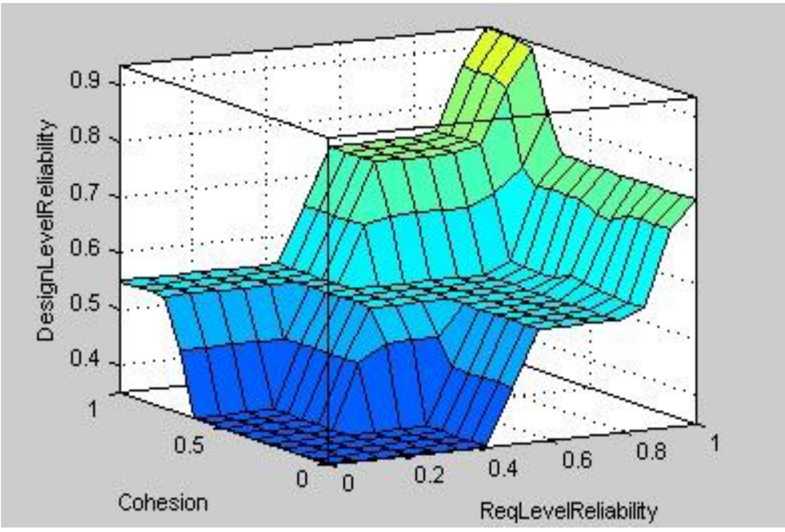


Figure 5.19 Sensitivity of DLR with respect to Req. Level Reliability and Cohesion

5.3.18 Sensitivity of DLR with respect to change in RLR & IM

Looking at the values of the following table 5.18 and the figure 5.20, it can be easily noticed that for any constant value of CoM, CM and EM, both the metric RLR and IM does not have very significant impact on the DLR. When the values of RLR and IM increase, it does not affect DLR much.

Table 5.18 Sensitivity of DLR with respect to Req. Level Reliability and Inheritance

EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
RLR, IM	DLR	RLR, IM	DLR	RLR, IM	DLR	RLR, IM	DLR	RLR, IM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.550
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.550
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.550	0.4	0.550
0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550
0.8	0.350	0.8	0.350	0.8	0.488	0.8	0.667	0.8	0.688
1.0	0.350	1.0	0.550	1.0	0.750	1.0	0.750	1.0	0.750

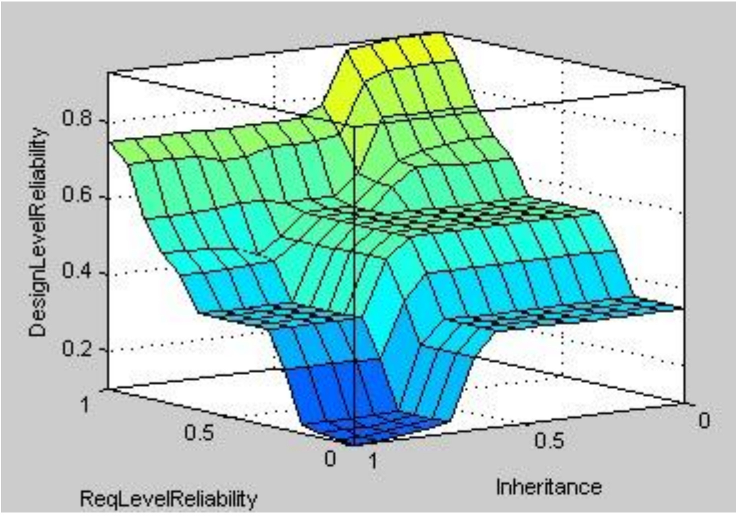


Figure 5.20 Sensitivity of DLR with respect to Req. Level Reliability and Inheritance

5.3.19 Sensitivity of DLR with respect to change in RLR & CM

Looking at the values of the following table 5.19 and the figure 5.21, it can be easily noticed that for any constant value of CoM, IM and EM, both the metric RLR and CM does not have very significant impact on the DLR. When the values of RLR and CM increase, it does not affect DLR significantly.

Table 5.19 Sensitivity of DLR with respect to Req. Level Reliability and Coupling

IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
RLR, CM	DLR	RLR, CM	DLR	RLR, CM	DLR	RLR, CM	DLR	RLR, CM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.550
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.550
0.4	0.350	0.4	0.350	0.4	0.550	0.4	0.550	0.4	0.550
0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.550
0.8	0.488	0.8	0.467	0.8	0.488	0.8	0.667	0.8	0.688
1.0	0.550	1.0	0.550	1.0	0.550	1.0	0.750	1.0	0.750

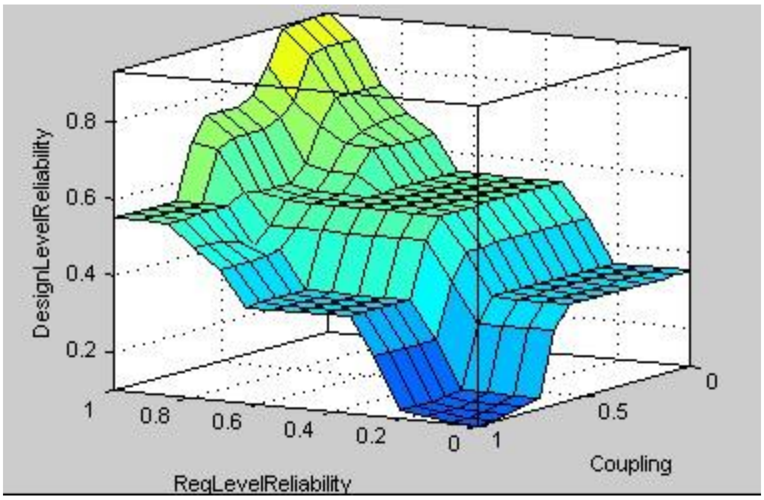


Figure 5.21 Sensitivity of DLR with respect to Req. Level Reliability and Coupling

5.3.20 Sensitivity of DLR with respect to change in EM & CoM

Looking at the values of the above table 5.20 and the figure 5.22, it can be easily noticed that for any constant value of IM, CM and RLR, both the metric EM and CoM has a positive impact on the DLR. When the values of EM and CoM increase, it forces the DLR to increase also. In other words, the developing software will be more reliable if the OOD has higher level of Cohesion as well as Encapsulation.

Table 5.20 Sensitivity of DLR with respect to Cohesion and Encapsulation

IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
RLR = 0%		RLR = 25%		RLR =50%		RLR = 75%		RLR = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
EM, CoM	DLR	EM, CoM	DLR	EM, CoM	DLR	EM, CoM	DLR	EM, CoM	DLR
0.0	0.350	0.0	0.350	0.0	0.235	0.0	0.121	0.0	0.350
0.2	0.350	0.2	0.350	0.2	0.235	0.2	0.121	0.2	0.350
0.4	0.550	0.4	0.550	0.4	0.550	0.4	0.450	0.4	0.550
0.6	0.550	0.6	0.550	0.6	0.550	0.6	0.450	0.6	0.550
0.8	0.922	0.8	0.916	0.8	0.650	0.8	0.650	0.8	0.750
1.0	0.937	1.0	0.916	1.0	0.650	1.0	0.650	1.0	0.750

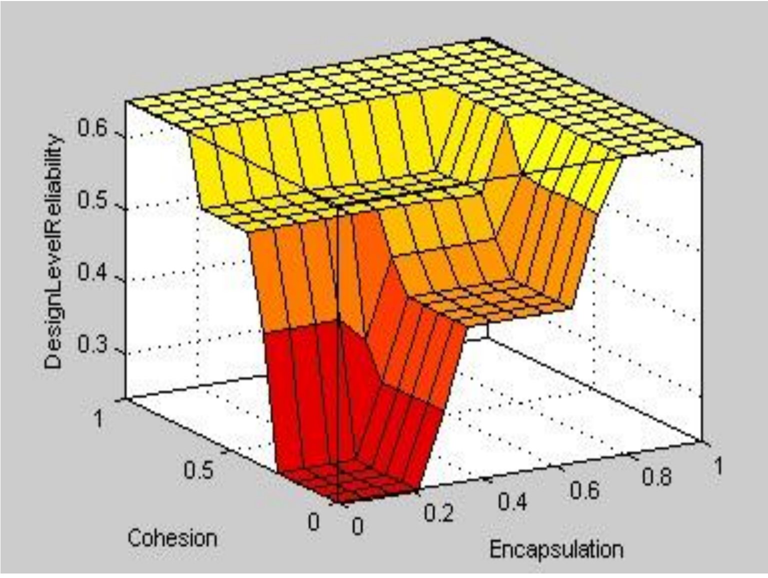


Figure 5.22 Sensitivity of DLR with respect to Cohesion and Encapsulation

5.3.21 Sensitivity of DLR with respect to change in EM & IM

Looking at the values of the following table 5.21 and the figure 5.23, it can be easily noticed that for any constant value of RLR, CM and CoM, the metric values of EM and IM has neither positive nor negative impact on the RLR. When the values of EM and IM increase, they do not affect DLR significantly.

Table 5.21 Sensitivity of DLR with respect to Encapsulation and Inheritance

RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
EM, IM	DLR	EM, IM	DLR	EM, IM	DLR	EM, IM	DLR	EM, IM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.550	0.0	0.750
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.550	0.2	0.750
0.4	0.114	0.4	0.127	0.4	0.550	0.4	0.650	0.4	0.750
0.6	0.114	0.6	0.127	0.6	0.550	0.6	0.650	0.6	0.750
0.8	0.350	0.8	0.350	0.8	0.450	0.8	0.650	0.8	0.750
1.0	0.350	1.0	0.350	1.0	0.450	1.0	0.650	1.0	0.750

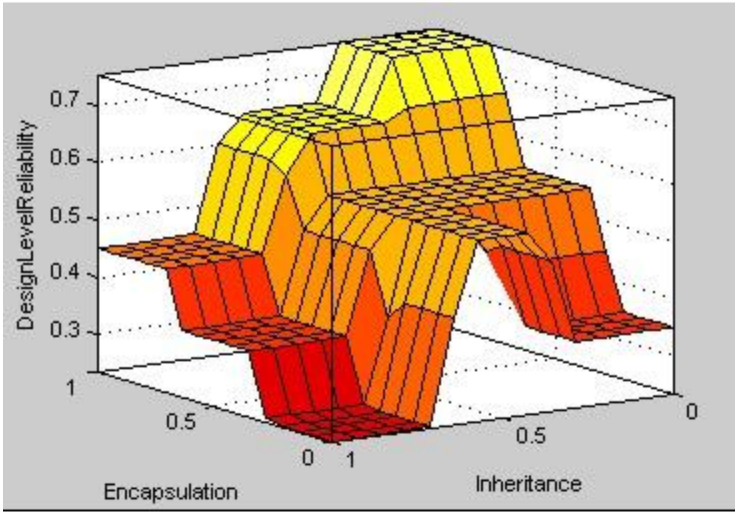


Figure 5.23 Sensitivity of DLR with respect to Encapsulation and Inheritance

5.3.22 Sensitivity of DLR with respect to change in EM & CM

Looking at the values of the following table 5.22 and the figure 5.24, it can be easily noticed that for any constant value of RLR, IM and CoM, the metric values of EM and CM has neither positive nor negative impact on the DLR. When the values of EM and CM increase, they do not affect DLR significantly.

Table 5.22 Sensitivity of DLR with respect to Encapsulation and Coupling

IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
EM, CM	DLR	EM, CM	DLR	EM, CM	DLR	EM, CM	DLR	EM, CM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.650	0.0	0.937
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.650	0.2	0.922
0.4	0.109	0.4	0.127	0.4	0.550	0.4	0.650	0.4	0.928
0.6	0.114	0.6	0.127	0.6	0.550	0.6	0.650	0.6	0.925
0.8	0.350	0.8	0.350	0.8	0.450	0.8	0.650	0.8	0.750
1.0	0.350	1.0	0.350	1.0	0.450	1.0	0.650	1.0	0.750

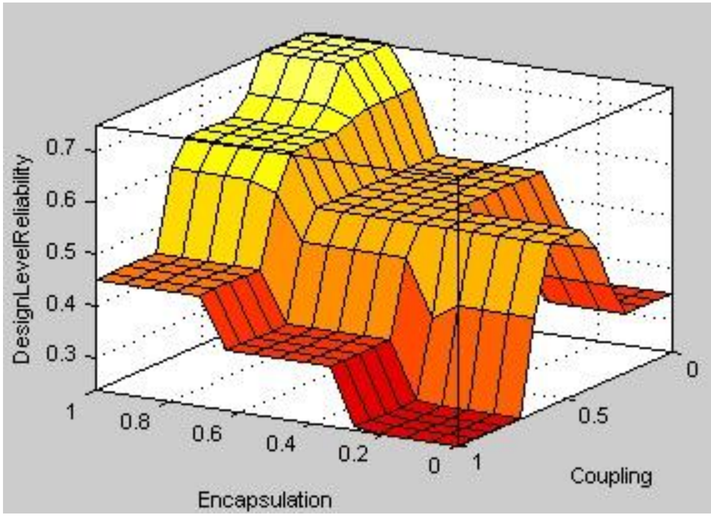


Figure 5.24 Sensitivity of DLR with respect to Encapsulation and Coupling

5.3.23 Sensitivity of DLR with respect to change in IM & CoM

Looking at the values of the following table 5.23 and the figure 5.25, it can be easily noticed that for any constant value of RLR, EM and CM, the metric values of IM and CoM has neither positive nor negative impact on the DLR. When the values of IM and CoM increase, they do not affect DLR significantly.

Table 5.23 Sensitivity of DLR with respect to Inheritance and Cohesion

RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
CM = 0%		CM = 25%		CM = 50%		CM = 75%		CM = 100%	
IM, CoM	DLR	IM, CoM	DLR	IM, CoM	DLR	IM, CoM	DLR	IM, CoM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.650	0.0	0.937
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.650	0.2	0.925
0.4	0.114	0.4	0.127	0.4	0.550	0.4	0.550	0.4	0.750
0.6	0.114	0.6	0.127	0.6	0.550	0.6	0.550	0.6	0.750
0.8	0.350	0.8	0.350	0.8	0.550	0.8	0.650	0.8	0.750
1.0	0.350	1.0	0.350	1.0	0.550	1.0	0.650	1.0	0.750

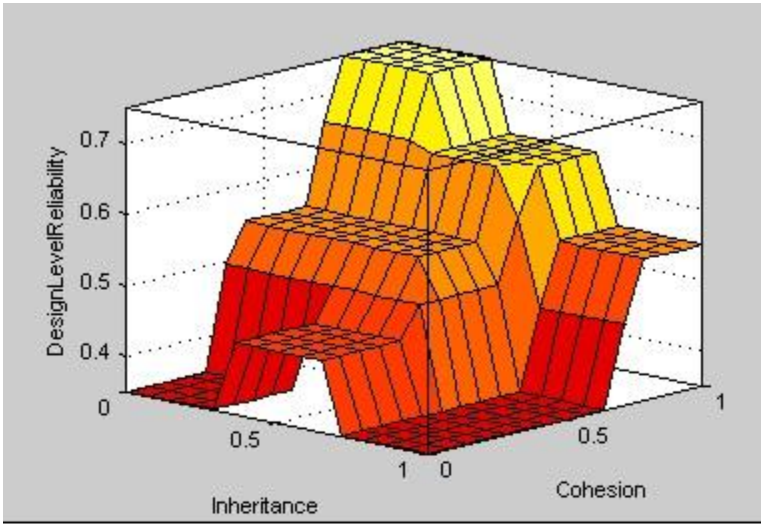


Figure 5.25 Sensitivity of DLR with respect to Inheritance and Cohesion

5.3.24 Sensitivity of DLR with respect to change in CM & CoM

Looking at the values of the following table 5.24 and the figure 5.26, it can be easily noticed that for any constant value of RLR, EM and IM, the metric values of CM and CoM has neither positive nor negative impact on the DLR. When the values of CM and CoM increase, they do not affect DLR significantly.

Table 5.24 Sensitivity of DLR with respect to Coupling and Cohesion

RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
IM = 0%		IM = 25%		IM = 50%		IM = 75%		IM = 100%	
CM, CoM	DLR	CM, CoM	DLR	CM, CoM	DLR	CM, CoM	DLR	CM, CoM	DLR
0.0	0.350	0.0	0.350	0.0	0.350	0.0	0.650	0.0	0.937
0.2	0.350	0.2	0.350	0.2	0.350	0.2	0.650	0.2	0.925
0.4	0.114	0.4	0.127	0.4	0.550	0.4	0.650	0.4	0.750
0.6	0.114	0.6	0.127	0.6	0.550	0.6	0.650	0.6	0.750
0.8	0.350	0.8	0.350	0.8	0.450	0.8	0.650	0.8	0.750
1.0	0.350	1.0	0.350	1.0	0.450	1.0	0.650	1.0	0.750

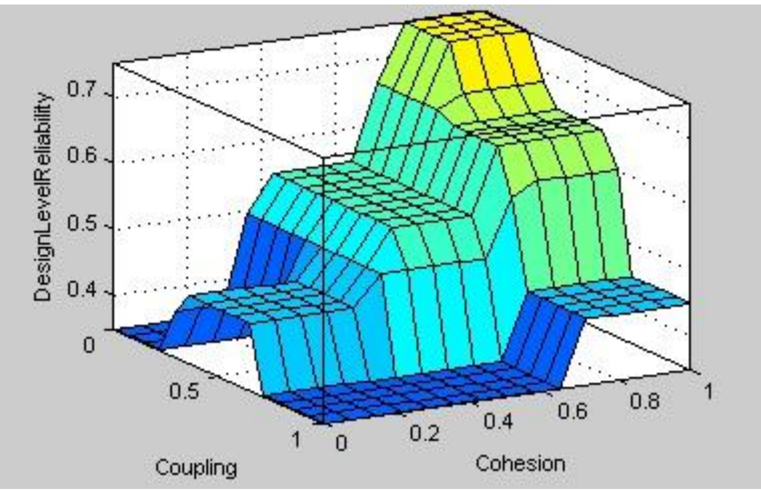


Figure 5.26 Sensitivity of DLR with respect to Coupling and Cohesion

5.3.25 Sensitivity of DLR with respect to change in IM & CM

Looking at the values of the following table 5.25 and the figure 5.27, it can be easily noticed that for any constant value of EM, CoM and RLR, both the metric CM and IM has a negative impact on the DLR. When the value of CM and IM increases, it forces the DLR to decrease. In other words, Reliability of the software will decrease as the coupling as well as inheritance increases in the object oriented design.

Table 5.25 Sensitivity of DLR with respect to Inheritance and Coupling

RLR = 0%		RLR = 25%		RLR = 50%		RLR = 75%		RLR = 100%	
EM = 0%		EM = 25%		EM = 50%		EM = 75%		EM = 100%	
CoM = 0%		CoM = 25%		CoM = 50%		CoM = 75%		CoM = 100%	
IM, CM	DLR	IM, CM	DLR	IM, CM	DLR	IM, CM	DLR	IM, CM	DLR
0.0	0.350	0.0	0.350	0.0	0.750	0.0	0.916	0.0	0.937
0.2	0.350	0.2	0.350	0.2	0.750	0.2	0.916	0.2	0.925
0.4	0.114	0.4	0.127	0.4	0.550	0.4	0.813	0.4	0.925
0.6	0.114	0.6	0.127	0.6	0.550	0.6	0.916	0.6	0.925
0.8	0.114	0.8	0.127	0.8	0.350	0.8	0.650	0.8	0.750
1.0	0.096	1.0	0.127	1.0	0.350	1.0	0.650	1.0	0.750

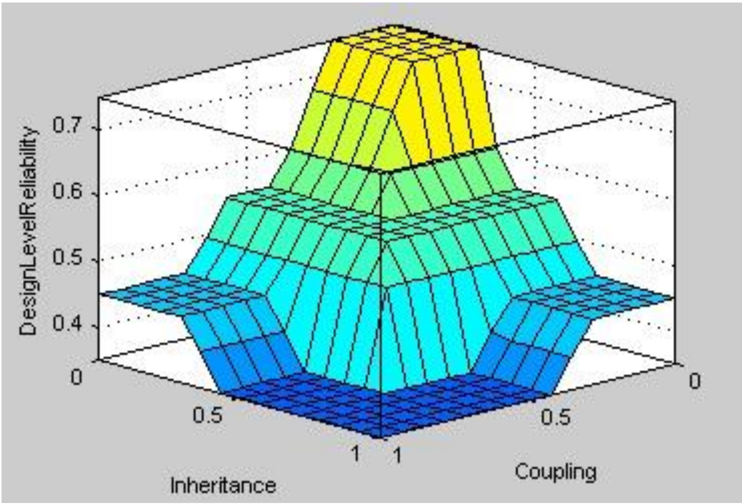


Figure 5.27 Sensitivity of DLR with respect to Inheritance and Coupling

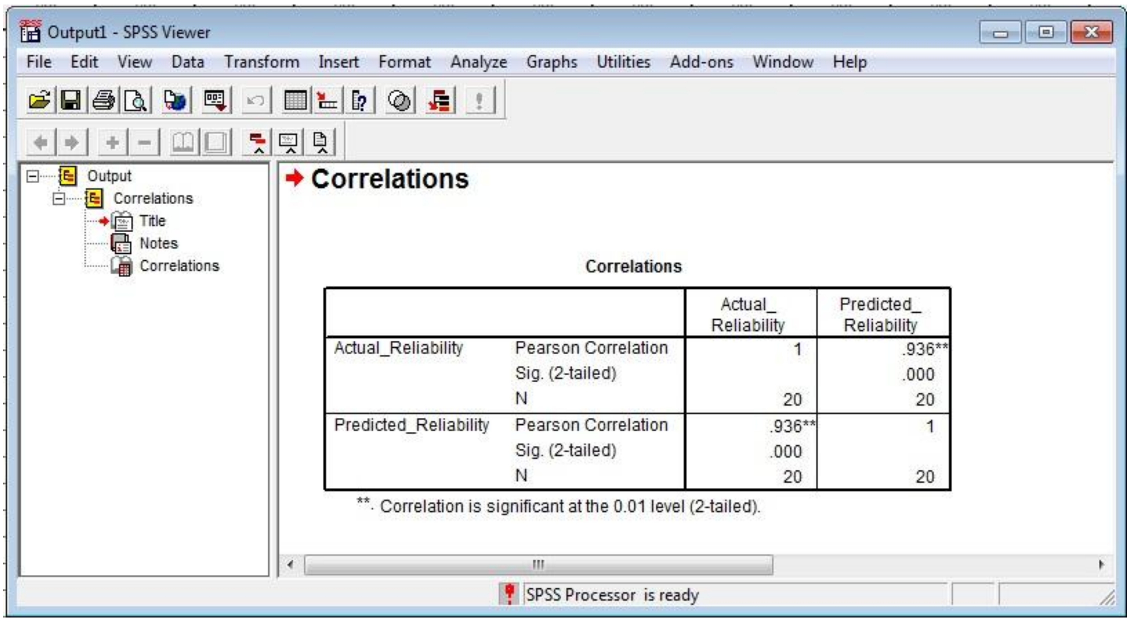
5.4 EXPERIMENTAL VALIDATION

This section of the chapter statistically validates the proposed model (ESRPM), by calculating the Pearson's correlation coefficient between the actual reliability values (already known) and the defuzzified (predicted) values of Design Level Reliability (DLR).

Table 5.26 Predicted and Actual Reliability Values

S.No.	Project Number	Reliability Predicted by the Proposed Model (Defuzzified Value)	Actual Reliability
1	P1	0.832	0.9
2	P2	0.721	0.9
3	P3	0.912	0.9
4	P4	0.600	0.75
5	P5	0.750	0.75
6	P6	0.587	0.55
7	P7	0.750	0.75
8	P8	0.550	0.55
9	P9	0.586	0.55
10	P10	0.750	0.75
11	P11	0.629	0.55
12	P12	0.614	0.55
13	P13	0.565	0.55
14	P14	0.752	0.75
15	P15	0.761	0.55
16	P16	0.320	0.35
17	P17	0.330	0.35
18	P18	0.350	0.35
19	P19	0.131	0.15
20	P20	0.210	0.15

In order to validate the proposed model (ESRPM), DLR has been computed using the fuzzy toolbox of MATLAB, for 20 software projects, those are currently in operation. These calculated values are presented in the Table 5.26, along with the corresponding actual reliability values. Now to ensure the quantifying ability of the model Pearson's correlation coefficient has been computed, between predicted and actual reliability.



Correlations

		Actual_ Reliability	Predicted_ Reliability
Actual_Reliability	Pearson Correlation	1	.936**
	Sig. (2-tailed)		.000
	N	20	20
Predicted_Reliability	Pearson Correlation	.936**	1
	Sig. (2-tailed)	.000	
	N	20	20

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 5.28 SPSS Correlation Analysis

The correlation has been computer through SPSS, and its value is (**0.936)** as shown figure 5.28 and Table 5.27. It is evident from the correlation value, that the reliability predicted by the ESRPM is strongly correlated with the already known values of reliability. Therefore, it can be concluded that the proposed model is quantifying reliability quiet efficiently.

Table 5.27 Pearson Correlation between Reliability Values

	Reliability Calculated	**Actual Reliability**
Reliability Calculated	1	0.936
Actual Reliability	0.936	1

5.5 MEASURES OF PREDICTIVE ACCURACY

In this section of the chapter the researcher describes the various prediction accuracy measures. After reviewing the literature, it has been found that the following are the predictive accuracy measures used by majority of researchers in most of the studies.

i. Magnitude of Relative Error (MRE);

ii. Mean Magnitude of Relative Error (MMRE);

iii. Balanced MMRE (BMMRE);

iv. Median Magnitude of Relative Error (MdMRE);

v. Prediction at Level q (Pred(q)).

(i) MRE (Magnitude of Relative Error)

MRE is a normalized measure of the discrepancy between actual values and predicted values of a dependent variable (Kitchenham et al. 2001). It is defined in Equation 5.1.

$$MRE = \frac{|\,actual\ value - predicted\ value\,|}{actual\ value} \qquad \textbf{5.1}$$

Where actual value is the value of the dependent variable as observed in the data set and predicted value is the corresponding predictive value obtained from the model itself.

(ii) MMRE (Mean Magnitude of Relative Error)

The Mean Magnitude of Relative Error (MMRE) is probably the most widely used evaluation criterion for assessing the performance of competing software prediction models. One purpose of MMRE is to assist in the selection of the best model (Kitchenham et al. 2001). The Mean Magnitude of Relative Error is defined in Equation 5.2.

$$MMRE = \frac{1}{n}\sum_{i=1}^{i=n} MRE_i \qquad \textbf{5.2}$$

Where n is the number of observations in the data set. MMRE is regarded as a versatile assessment criterion and has a number of advantages. MMRE measures the average relative discrepancy, which is equivalent to the average error relative to the actual effort in the prediction. It can be used to make comparisons across data sets and all kinds of prediction models. The MMRE is also independent of measurement units and is scale independent (Conte et al., 1986; Walkerden and Jeffery, 1999). It has been the de facto standard as an accuracy measure for prediction models. It is regularly used to compare the accuracy of quality estimation models and modeling techniques (Walkerden and Jeffery, 1999). The value of MMRE is strongly influenced by a few very high relative error (RE) values. Some times MMRE is expressed in %. However, this study follows the definition given in Equation 5.2.

(iii) BMMRE (Balanced Mean Magnitude of Relative Error)

MMRE is unbalanced and penalizes overestimates more than the underestimates. For this reason, a balanced mean magnitude of relative error measure is also considered which is as follows (Chulani et al. 1999; Fenton et al., 2008):

$$\text{BMMRE} = \frac{1}{n}\sum_{i=1}^{n}\frac{|y_i - \hat{y}_i|}{\text{Min}\,(y_i, \hat{y}_i)} \qquad \textbf{5.3}$$

(iv) MdMRE (Median Magnitude of Relative Error)

As mentioned in the above paragraph that the MMRE is suffering from the shortcoming of strongly influencing by extreme values of MREs, therefore to overcome this shortcoming of MMRE, a measure Median Magnitude of Relative Error (MdMRE) is introduced. It is the measure that is unaffected by the extreme values.

(v) Prediction at Level q (Pred(q))

Pred is a measure of the proportion of the predicted values that have an MRE less than or equal to a specified value. It is defined as in Equation 5.3 (Fenton and Pfleeger, 1998).

$$Pred(q) = \frac{k}{n} \qquad \textbf{5.4}$$

Where q is the specified value, k is the number of cases whose MRE is less than or equal to q, and n is the total number of cases in the dataset. In this study, Pred(0.25) is used because it is the commonly used pred measure in the literature (De Lucia et al., 2005).

Table 5.28 MRE for Reliability Model (ESRPM)

S.No.	Project Number	Reliability Predicted by the Proposed Model (Defuzzified Value)	Actual Reliability	Magnitude of Relative Error (MRE)
1	P1	0.832	0.9	0.076
2	P2	0.721	0.9	0.199
3	P3	0.912	0.9	0.013
4	P4	0.600	0.75	0.200
5	P5	0.750	0.75	0.000
6	P6	0.587	0.55	0.067
7	P7	0.750	0.75	0.000
8	P8	0.550	0.55	0.000
9	P9	0.586	0.55	0.065
10	P10	0.750	0.75	0.000
11	P11	0.629	0.55	0.144
12	P12	0.614	0.55	0.116
13	P13	0.565	0.55	0.027
14	P14	0.752	0.75	0.003
15	P15	0.761	0.55	0.384
16	P16	0.320	0.35	0.086
17	P17	0.330	0.35	0.057
18	P18	0.350	0.35	0.000
19	P19	0.131	0.15	0.127
20	P20	0.210	0.15	0.400

For an effort prediction model to be considered accurate, MMRE ≤ 0.25 (Conte et. al, 1986) and pred(0.25) ≥ 0.75 or pred(0.30) ≥ 0.70 is suggested in the literature (MacDonell, 1997).

5.6 PREDICTIVE ACCURACY OF RELIABILITY MODEL (ESRPM)

In order to compute the predictive accuracy of the model, reliability of software projects belonging to the data set has been calculated using the fuzzy toolbox of MATLAB. The next task is to compute the Magnitude of Relative Error (MRE) for them using the equation 5.1. The values of actual reliability, reliability predicted through the model (ESRPM) and the corresponding MREs for all the 20 projects are shown in Table 5.28. Now after calculating the MRE values, the next task is to compute the Mean of these MRE values i.e. MMRE (Mean Magnitude of Relative Error).

$$\text{Sum of } MRE_1, MRE_2, \ldots\ldots. MRE_{20} = \mathbf{1.964}$$

$$\mathbf{MMRE = 1.964/20 = 0.09818}$$

The value of MMRE is quite encouraging and falls well below the acceptance threshold value of **0.25**. Because Conte et. al (1986) suggests an MMRE ≤ 0.25 as acceptable prediction accuracy of software development effort prediction models. After computing the MMRE, next important accuracy measures to be computed are Balanced Mean Magnitude of Relative Error (BMMRE) and Mean Absolute Percentage Error MAPE as shown in Table 5.29 and 5.30 respectively.

Table 5.29 BMMRE for Reliability Model (ESRPM)

S.No.	Project Number	Reliability Predicted by the Proposed Model (Defuzzified Value)	Actual Reliability	Balanced MRE (BMRE)
1	P1	0.832	0.9	0.082
2	P2	0.721	0.9	0.248
3	P3	0.912	0.9	0.013
4	P4	0.600	0.75	0.250
5	P5	0.750	0.75	0.000
6	P6	0.587	0.55	0.067
7	P7	0.750	0.75	0.000
8	P8	0.550	0.55	0.000
9	P9	0.586	0.55	0.065
10	P10	0.750	0.75	0.000
11	P11	0.629	0.55	0.144
12	P12	0.614	0.55	0.116
13	P13	0.565	0.55	0.027
14	P14	0.752	0.75	0.003
15	P15	0.761	0.55	0.384
16	P16	0.320	0.35	0.094
17	P17	0.330	0.35	0.061
18	P18	0.350	0.35	0.000
19	P19	0.131	0.15	0.145
20	P20	0.210	0.15	0.400

Table 5.30 MAPE for Reliability Model (ESRPM)

S.No.	Project Number	Reliability Predicted by the Proposed Model (Defuzzified Value)	Actual Reliability	Percentage Error
1	P1	0.832	0.9	7.556
2	P2	0.721	0.9	19.889
3	P3	0.912	0.9	1.333
4	P4	0.600	0.75	20.000
5	P5	0.750	0.75	0.000
6	P6	0.587	0.55	6.727
7	P7	0.750	0.75	0.000
8	P8	0.550	0.55	0.000
9	P9	0.586	0.55	6.545
10	P10	0.750	0.75	0.000
11	P11	0.629	0.55	14.364
12	P12	0.614	0.55	11.636
13	P13	0.565	0.55	2.727
14	P14	0.752	0.75	0.267
15	P15	0.761	0.55	38.364
16	P16	0.320	0.35	8.571
17	P17	0.330	0.35	5.714
18	P18	0.350	0.35	0.000
19	P19	0.131	0.15	12.667
20	P20	0.210	0.15	40.000

Sum of $BMRE_1$, $BMRE_2$,…….$BMRE_{20}$ = **2.099**

Balanced MMRE (BMMRE) = 2.099/20 = 0.104951

Sum of percentage errors = **196.360**

Mean Absolute Percentage Error (MAPE) = 196.360/20 = 9.818023

Like MMRE the values of BMMRE and MAPE are also comes out very promising, and reemphasizing that the model has a good predictive accuracy. After computing the MMRE and BMMRE, the quartiles of MRE distribution (i.e. MdMRE, P_{25} & P_{75}) are also calculated. In order to compute MdMRE (Median Magnitude of Relative Error), P_{25} (Ist Quartile) & P_{75} (IIIrd Quartile), the values of MREs are arranged in ascending order.

Median Magnitude of Relative Error (MdMRE) = 0.066

P_{25} (Ist Quartile) = 0.0000

P_{75} (IIIrd Quartile) = 0.135152

The values of MdMRE P_{25} and P_{75} are also align with other values. The Pred(0.25) for the model is also computed, that reports the percentage of the estimates with an MRE less than or equal to 0.25.

Pred(0.25) = 0.90 (90%)

The above value of Pred(0.25) indicating that the 90% of the predicted values by the reliability model (ESRPM) have MREs less than of equal to 0.25, that is quiet encouraging.

Looking at the values of various accuracy measures, it is evident that the prediction ability of the reliability model ESRPM is quiet accurate. Therefore it can be concluded that the model can be used to accurately predict the design level reliability for any Object Oriented software before its coding starts.

5.7 CONCLUSION

The chapter has validated the developed model and also ensures its reliability prediction capability. Initially the chapter has justified the various constituents of the models, in the light of theoretical concepts. In the subsequent section, quantifying ability of model has been validated with the help of statistical measures. For this Pearson's correlation coefficient has been computed, between predicted and actual reliability values. Looking at the correlation values it is evident that the values predicted through ESRPM are highly correlated with the already known values. Subsequently the chapter provides the brief description of various accuracy measures and comprehensively discussed the model's predictive accuracy. Looking at the values of various measures it is evident that the models are quiet accurate.