Effect of Schedule Compression on Project Effort in COCOMO II Model for Highly Compressed Schedule Ratings

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Abstract. This paper presents the effect of 'schedule compression' on software project management effort using COCOMO II (Constructive Cost Model II), considering projects which require more than 25 percent of compression in their schedule. At present, COCOMO II provides a cost driver for applying the effect of schedule compression or expansion on project effort. Its maximum allowed compression is 25 percent due to its exponential effect on effort. This research study is based on 15 industry projects and consists of two parts. In first part, the Compression Ratio (CR) is calculated using actual and estimated project schedules. CR is the schedule compression percentage that was applied in actual which is compared with rated schedule compression percentage to find schedule estimation accuracy. In the second part, a new rating level is derived to cover projects which provide schedule compression higher than 25 percent.

Keywords: COCOMO II, Project Schedule Compression, Compression Ratio, Schedule Estimation Accuracy, Rating Level

1 Introduction

COCOMO II is a model that allows one to estimate the cost, effort, and schedule when planning a new software development activity. It consists of three sub-models [1], each one offering increased fidelity the further along one is in the project planning and design process. COCOMO II is the only model in which project scheduling has its own effect on the overall cost. Among its seventeen cost drivers [2], one is used for scheduling, which is named as SCED (Schedule Cost Driver). This driver has five rating levels (Table1) depending on the project schedule compression, expansion or nominal schedule. The ratings according to COCOMO II research are based on study of 161 industry projects and ranges from 25 percent compression to 60% expansion of schedule [3].

It has been studied that the range of compression rating levels in COCOMO II is from very low (75% of nominal) to very high (160% of nominal). Nominal schedule is the schedule without any compression or stretch-out [4]. A project with schedule of less than 100% will fall in the area of compression and a project with greater than 100% of schedule will fall in the area of stretch-out.

In COCOMO II, an increase in compression, of more than 25% will approximately increase project's cost to 50%. It has been analyzed that increasing the compression rate increases project cost exponentially. Due to this reason, a maximum compression of 25% has been included. Above these compression ratings, the project is considered in impossible region where either its schedule cannot be compressed anymore, or the cost overruns take place.

Table 1. COCOMO II SCED Cost Driver Rating Scale [3]

SCED Descriptors	***75% of nominal***	***85% of nominal***	***100% of nominal***	***130% of nominal***	***160% of nominal***
Rating Level	Very Low	Low	Nominal	High	Very High
Effort Multiplier	1.43	1.14	1.00	1.00	1.00

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2 Experimental Investigation

A study of two experiments, extracted from Boehm's *et al*. [4] research, is included in this study. The first experiment is about checking whether in estimating project effort, the SCED cost driver is rated accurately or not, and the second experiment is calculating Ideal Effort Multiplier (IEM) of SCED for compressed schedules of more than 25%. This IEM value is then applied on projects to check its accuracy level. In order to carry out these experiments, 15 industrial projects of leading software houses of Karachi, Pakistan have been assessed. The experiments are described as follows:

2.1 Experiment I: SCED Rating Quality

This experiment is performed on COCOMO II datasets of 15 industry projects to determine the rating of SCED quality. Since it is recognized that the SCED rating in every data point comes from a subjective judgment, the authors have tried to logically derive a more accurate SCED rating by analyzing the data. To calculate the Derived SCED, estimated effort without Rated SCED using Equation1 are computed and its results are used to calculate the estimated schedule Total time to develop TDEV_est by using Equation2. Further Equation 3 is used to calculate the schedule compression ratios CR to determine the derived SCED.

$$Estimated\_effort = A * (KSLOC)^{(B+0.01*(\sum_{i=1} SF_i))} * (\prod_{j=1}^{16} EM\_But\_SCED_j) \quad (1)$$

$$TDEV\_est = C * (PM_{est})^{(D+0.2*(E-B))} \quad (2)$$

$$CR = TDEV_{actual} / TDEV_{est} \quad (3)$$

Where,

i. A, B are model constants, calibrated for each different version of COCOMO model.
ii. C is schedule coefficient that can be calibrated
iii. D is scaling base-exponent for schedule that can be calibrated
iv. E is the scaling exponent for the effort equation
v. SF are five scale factors including PMAT, PREC, TEAM, FLEX, and RESL
vi. EM_But_SCED are effort multipliers except SCED, including RELY, DATA, CPLX, RUSE, DOCU, TIME, STOR, PVOL, ACAP, PCAP, PCON, APEX, PLEX, LTEX, TOOL, and SITE
vii. A nominal Schedule is under no pressure, which means no schedule compression or expansion; initially set to 1.0.

SCED rating quality can be obtained for each project, by comparing the Derived SCED and the Rated SCED. The five steps being performed in this experiment are shown in Figure1 and are defined as:

Step 1: Compute estimated effort assuming that schedule is nominal. Formula in Equation2 shows estimated effort assuming nominal schedule (SCED is equal to 1).

Step 2: Compute estimated schedule TDEV_est. Formula in Equation 2 shows estimated schedule using estimated effort, computed in step1. TDEV_est is estimated time to development.

Step 3: Compute Actual Schedule Compression/Stretch-out Ratio (SCR). Every data point comes with an actual schedule. For example, in COCOMO II, it is named $\boldsymbol{TDEV}_{\text{actual}}$ (time to development).

Actual Schedule Compression/Stretch-out Ratio (SCR) can be easily derived through the following equation:

SCR = Actual Schedule / Derived Schedule (4)

For example, if a project's TDEV is 6 months, and the estimated nominal schedule TDEV_est is about 12 months, then we consider the actual schedule compression as 50% (= 6/12).

Step 4: Obtain "derived" SCED rating. COCOMO II SCED Driver Definition Rating [4] (Table 3) has defined rating ranges. Using Equation 6 (discussed in 2.2), compute the actual schedule compression/stretch-out ratio, look up in the SCED driver definition table and check for the closest matched SCED rating. Then a new set of SCED ratings is produced which reflects the project's schedule compression level more accurately.

Step 5: Compare “derived” and “rated” SCED to analyze SCED Rating Quality. The comparison of derived SCED and rated SCED will be done. The above steps will result in a matrix table showing a comparison of derived SCED and rated SCED rating levels which will give clear picture of SCE rating quality observed after performing experiment I.

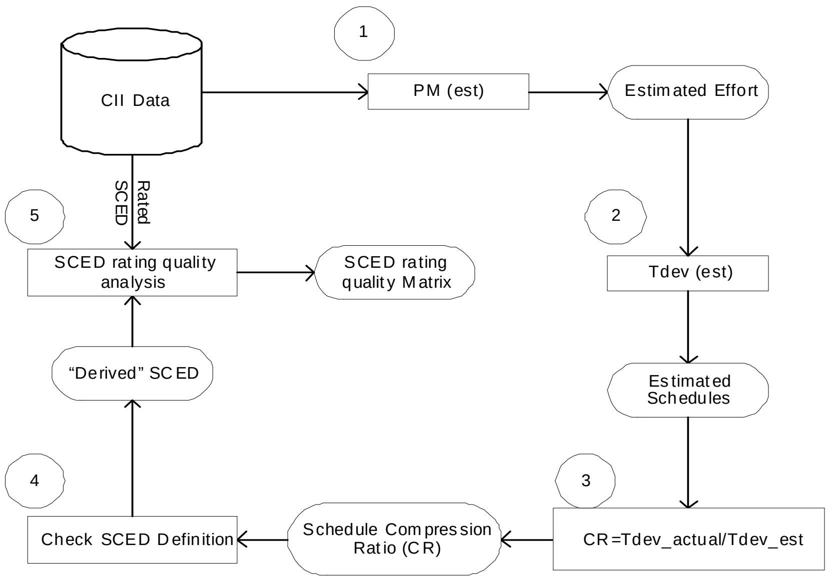

Fig.1. SCED Rating Quality Study Steps

2.2 Experiment II: Ideal Effort Multiplier (IEM) Analysis on SCED

SCED cost driver is one of the important cost drivers in COCOMO II. Methods have been established to normalize out contaminating effects of individual cost driver attributes, in order to get a clear picture of the contribution of that driver (in this case, the SCED) on development productivity [5]. It has been slightly modified the original definition to give it a meaning of working definition:

For the given project P, compute the estimated development effort using the COCOMO estimation procedure, with one exception: do not include the effort multiplier for the cost driver attribute (CDA) being analyzed. Call this estimate PM(P, CDA). Then the ideal effort multiplier, IEM(P, CDA), for this project/cost-driver combination is defined as the multiplier which, if used in COCOMO, would make the estimated development effort for the project equal to its actual development effort PM(P, actual). i.e.,

$$IEM(P, SCED) = PM(P, actual) / PM(P, SCED) \quad (5)$$

2.2.1 Steps for IEM-SCED analysis

The following steps (Figure 2) were performed to complete the IEM-SCED analysis on the COCOMO II database.

Step1: Compute the PM(P, CDA), using the following formula

$$PM(P,CDA) = A*(KSLOC)^{(B+0.01*(\sum_{i=1}^{5} SF_i))} * (\prod_{j=1}^{16} EM\_But\_SCED_j) \quad (6)$$

Step 2: Compute the IEM(P, CDA) using Equation (6)

Step 3: Group IEM(P, CDA) by the same SCED rating (i.e. VL, L, N, H, VH)

Step 4: Compute the median value for each group as IEM-SCED value for that rating. This step involves the computation of the median value of IEM-SCED for each rating level. This will give the new rating scale for extra-low level of SCED.

Step 5: Comparison of IEM results and COCOMO II

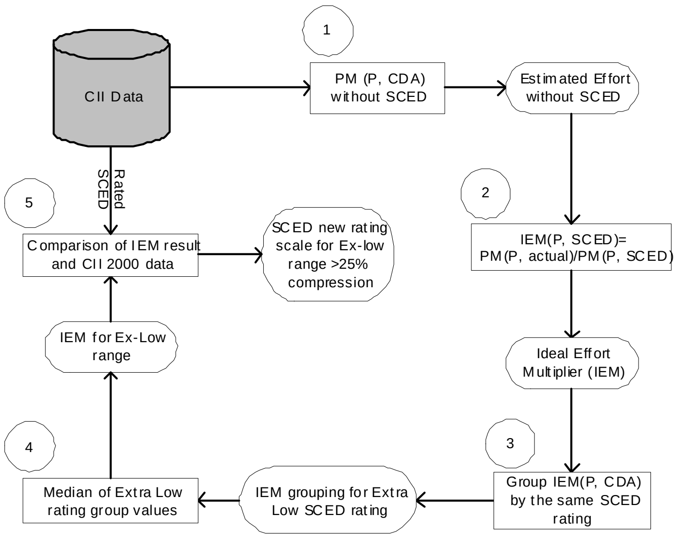

Fig. 2. IEM analysis Steps

3 Implementing Model

The above described experiments I and II with detailed steps, are being applied on dataset of 15 industry projects. These projects were estimated using COCOMO II Model, belonging to the leading software houses of Karachi, Pakistan.

The projects were developed using COCOMO II Model Estimation, which took place after the requirements and preliminary design was completed. Due to that reason COCOMO II's Post-architecture Model was used. Based on the datasets, Size of the 15 projects was calculated using Function Point Method as given in the following Table 2.

After calculating the size of projects, Effort estimation in Person Month (PM) calculated by using COCOMO II Post-Architecture Model equation:

$$PM = A*(SIZE)^B * (\prod EM_j) \quad (7)$$

We are taking SCED nominal; therefore total time for developing project can be calculated by following formula

$$TDEV = \left[3.67 * (\overline{PM})^{(0.28+0.2*(B-0.91))}\right] * (\frac{SCED\%}{100}) \qquad (8)$$

Table 2. Basic Information of the Projects considered, their derived, rated SCED and compression percentages

Project	***Project Name***	***Organization***	***Size (KLOC)***	***Derived SCED***	***Rated SCED***	***Derived % of compression w.r.t. Nominal***
Project 1	Prepaid Card Sales System	GO CDMA	48.86	VL	N	51%
Project 2	SITE Construction System	GO CDMA	37.31	VL	N	57%
Project 3	HR	Supernet Ltd	28.67	VL	L	68%
Project 4	MIS User Admin	Supernet Ltd	11.024	VL	N	60%
Project 5	Franchisee online	GO CDMA	23.95	VL	N	74%
Project 6	BTS Inventory	GO CDMA	33.97	VL	N	62.7%
Project 7	WNO	GO CDMA	7.473	VL	N	67.56%
Project 8	SME	GO CDMA	12.93	VL	N	62.42%
Project 9	SOP	Telecard Ltd.	8.162	VL	VL	65.83%
Project 10	LDI Installation System	GO CDMA	31.694	VL	N	68.69%
Project 11	Telco System	GO CDMA	24.115	VL	N	71.5%
Project 12	Complaints Management System	GO CDMA	41.49	VL	N	74.55%
Project 13	Promotional material management System	Telecard Ltd.	18.974	VL	VL	74.62%
Project 14	Corporate Stock Inventory mgmt System	Telecard Ltd.	23.53	VL	L	73.3%
Project 15	Customer Services IS	GO CDMA	35.404	VL	N	72.42%

Table 3. SCED Driver definition Ratings table

Rating	*Range*	*Median Value*	*Range*
VL	<0.77	0.77	(0, 0.77)
VL-L	>=0.77 <0.82	0.80	(0.77, 0.82)
L	>=0.82 <0.90	0.87	(0.82, 0.90)
L-	>=0.90 <0.95	0.93	(0.90, 0.95)
N	>=0.95 <1.10	1.03	(0.95, 1.10)
N-H	>=1.10 <1.22	1.16	(1.10, 1.22)
H	>=1.22 <1.37	1.30	(1.22, 1.37)
H-VH	>=1.37 <1.52	1.45	(1.37, 1.52)
VH	>=1.52	1.53	[1.52, >1.52)

Here TEDV is estimated total development time and it can be represented as TDEV(estimated), however total development time in actual can be represented as TDEV(actual). After having the TDEV(estimated) and TDEV(actual) values, schedule compression ratio of 15 projects was calculated by the following formula:

$$CR = \frac{TDEV(actual)}{TDEV(estimated)}$$

Table 3 is a standard index of rating levels provided by [4], [9], used here in order to know the rating of CR calculated above.

Calculations have been carried out to compute the actual CR of all the 15 projects. As the projects are of almost same working environment, therefore the SCALE FACTORS and COST DRIVERS rating values taken are the same for all the projects.

Table 4 shows a comparison of derived SCED and rated SCED. The rated SCED is obtained from the subjective judgment of development team at the time of effort estimation, while derived SCED is obtained from calculation of CR calculated from actual person months of project.

Table 2 shows a big difference between derived SCED and the rated SCED. The table further shows that the result of subjective judgment was very optimistic but was incorrect. In general, a project team does not consider SCED as important and use its default rating, i.e. Nominal rating and estimate project's cost and effort. But this should be considered seriously at the time of estimation, because a slight change of SCED level results in a huge change in cost and effort. As this is known fact that compression of schedule increases the project effort exponentially so this SCED cost driver has great importance. The SCED can be rated easily by dividing effort by total development time. A rating analysis has been performed in the form of matrix, counting each rating level's number of occurrences for derived and rated SCED both.

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Table 4 is a matrix representation of results in which, rows show derived SCED rating levels and columns show rated SCED rating levels. The intersection of each row and column is the number of occurrences counted from Table5. The circled value shows 11 occurrences of N ratings, as rated by subjective judgment but is derived to be Very Low ratings from Experiment1. This matrix is the final result of Experiment 1, i.e. “SCED accuracy analysis”.

After analysis of the matrix of Table 4, it has been proved that SCED is not rated accurately in estimating effort. Keeping in mind its impact on effort it should be rated correctly to get accurate results

3.1 Ideal Effort Multiplier (IEM)

This experiment is carried out to propose a new SCED rating level Extra-low and its respective effort multiplier.

Formula for calculating Ideal Effort Multiplier is as follows:

$$IEM(P, SCED) = \frac{PM(P, actual)}{PM(P, SCED)}$$ (see Equation 5)

Table 4. SCED Rating Quality Analysis in COCOMO II database

SCR	*(0, 0.77)*	*(0.77, 0.82)*	*(0.82, 0.90)*	*(0.90, 095)*	*(0.95, 1.10)*	*(1.10, 1.22)*	*(1.22, 1.37)*	*(1.37, 1.52)*	*(1.52, +)*
	VL	VL-L	L	L-N	N	N-H	H	H-VH	VH
VL	**2**	X	X	X	X	X	X	X	X
VL-L	X	X	X	X	X	X	X	X	X
L	**2**	X	X	X	X	X	X	X	X
L-N	X	X	X	X	X	X	X	X	X
N	**11**	X	X	X	X	X	X	X	X
N-H	X	X	X	X	X	X	X	X	X
H	X	X	X	X	X	X	X	X	X
H-VH	X	X	X	X	X	X	X	X	X
VH	X	X	X	X	X	X	X	X	X

SCED: Reported In Data (rows) — SCED: Derived from the experiment (columns)

The results of each project IEM are shown in the last column of Table 6. This multiplier is the perfect SCED multiplier for that particular project. If this is applied in the formula the estimated effort will become equal to the actual effort.

Table 5 shows that percentages of derived SCED are less than 75% of nominal. Here we can suggest a new rating level named Extra-Low which will cover the projects having compressions of more than 25%. The group of Extra-Low level rating is shown in Table 6a.

Given that extreme values (outliers) exist in our databases. Those outliers could give great impact to the mean values. To avoid that, the median value is used since it is not as sensitive to outliers.

To calculate the median of the group data of IEMs, first we have to sort them in ascending order as shown in Table6b. The mid-term will be the median in case of odd number of data records. In case of even data, two of the mid terms are taken and their mean value is calculated.

IEM value at 8th term is the median which is found to be 1.51. Hence the value 1.51 is the rating value for Extra Low range of SCED cost driver, as shown in Table 7.

Table 5. Results of IEM calculation

Project	***Derived %***	***TDEV (actual)***	***Staff***	***PM (actual)***	***PM (est) wout SCED***	***PM (est)***	***IEM***
P1	51%	6 mths	6	**36**	**23.8**	23.8	**1.51**
P2	57%	5 mths	6	**30**	**18.16**	18.16	**1.65**
P3	68%	4.5 mths	4	**18**	**11.65**	13.28	**1.54**
P4	60%	3.75 mths	2	**7.5**	**5.647**	5.647	**1.32**
P5	74%	4 mths	2	**8**	**3.63**	3.63	**2.20**
P6	62.7%	4 mths	2	**8**	**6.289**	6.289	**1.27**
P7	67.56%	3.75 mths	2	**7.5**	**3.968**	3.968	**1.89**
P8	62.42%	5 mths	3	**15**	**13.959**	13.959	**1.07**
P9	65.83%	3 mths	3	**9**	**5.36**	7.66	**1.67**
P10	68.69%	4.3mths	5	**21.5**	**15.43**	22.06	**1.39**
P11	71.5%	5.5 mths	3	**16.5**	**11.73**	11.73	**1.40**
P12	74.55%	6.75 mths	5	**33.75**	**20.20**	20.20	**1.67**
P13	74.62%	4 mths	3	**12**	**9.23**	13.20	**1.30**
P14	73.3%	4.25 mths	4	**17**	**11.45**	13.057	**1.48**
P15	72.4%	6.25 mths	5	**31.25**	**17.24**	17.24	**1.81**

Table 6a. IEM of projects

P1	***P2***	***P3***	***P4***	***P5***	***P6***	***P7***	***P8***	***P9***	***P10***	***P11***	***P12***	***P13***	***P14***	***P15***
1.51	1.65	1.54	1.32	2.20	1.27	1.89	1.07	1.67	1.39	1.40	1.67	1.30	1.48	1.81

Table 6b. Sorted IEM of projects and its median

P8	***P6***	***P13***	***P4***	***P10***	***P11***	***P14***	***P1***	***P3***	***P2***	***P9***	***P12***	***P15***	***P7***	***P5***
1.07	1.27	1.30	1.32	1.39	1.40	1.48	1.51	1.54	1.65	1.67	1.67	1.81	1.89	2.20

Table 7. COCOMO II SCED New rating scale

SCED Descriptors	*<75% of Nominal*	*75% of Nominal*	*85% of Nominal*	*100% of Nominal*	*130% of Nominal*	*160% of Nominal*
Rating Level	Extra Low	Very Low	Low	Nominal	High	Very High
Effort Multiplier	**1.5***	1.43	1.14	1.00	1.00	1.00

** derived through experiment*

4 Applying IEM (SCED) rating in effort estimation

To check the accuracy of IEM(SCED), new rating has been applied on the same projects and re-calculated effort with a change of SCED driver value equals to 1.51. The resulted effort is named IEM-PM(est) as shown in the last column of Table8.

Table 8. Calculation results of IEM-PM(est) using IEM(SCED) = 1.51

Project	***Schedule %***	***PM(actual)***	***PM(est)***	***IEM-PM(est)***
Project 1	51%	**36**	23.8	**36**
Project 2	57%	**30**	18.16	**27.43**
Project 3	68%	**18**	13.28	**17.59**
Project 4	60%	**7.5**	5.647	**8.52**
Project 5	74%	**4**	3.63	**5.48**
Project 6	62.7%	**8**	6.289	**9.5**
Project 7	67.56%	**7.5**	3.968	**6**
Project 8	62.42%	**15**	13.959	**21**
Project 9	65.83%	**9**	7.66	**8**
Project 10	68.69%	**21.5**	22.06	**23.3**
Project 11	71.5%	**16.5**	11.73	**17.71**
Project 12	74.55%	**33.75**	20.20	**30.502**
Project 13	74.62%	**12**	13.20	**13.94**
Project 14	73.3%	**17**	13.057	**17.29**
Project 15	72.4%	**31.25**	17.24	**26.03**

From Table 8 it is observed that estimated effort using new SCED rating is much closer to the actual effort than the previous estimation, and now on the basis of these results model accuracy will be calculated.

4.1 Calculating model accuracy with Magnitude of Relative Error (MRE)

The MRE [6], [7] as a percentage of the actual effort for a project is defined as:

$$MRE = \left| \frac{Effort_{ACTUAL} - Effort_{ESTIMATED}}{Effort_{ACTUAL}} \right| \quad (9)$$

In addition, we have used the measure prediction level Pred. This measure is often used in research studies [10], [11] and is a proportion of a given level of accuracy:

$$pred(l) = \frac{k}{N} \quad (10)$$

A common value for *l* is 0.25 [2], [8], which is used for this study as well. The Pred(0.25) gives the percentage of projects that were predicted with an MRE equal or less than 0.25. Conte *et al*. [2] suggests an acceptable threshold value for the mean MRE to be less than 0.25 and for Pred(0.25) greater or than 0.75. In general, the accuracy of an estimation technique is proportional to the Pred(0.25) and inversely proportional to the MRE and the mean MRE.

In Table 9, MRE is calculated using Equation 9. Actual and estimated effort is listed in the table. These two efforts are used to calculate MRE and the absolute value of the answer has to been taken. Table 9 shows two MREs, first one is without IEM(SCED), calculated using effort estimated using old SCED rating. Second one is with IEM(SCED) rating, this is calculated using effort estimated with IEM(SCED) rating value.

Table 9. Calculation results of MRE of PM(est) with and without IEM(SCED)

Project	*PM (actual)*	*PM(est)without Ex-Low rating*	*PM(est) with Ex-Low rating*	*MRE without IEM(SCED)*	*MRE with IEM(SCED)*
Project 1	36	23.8	36	0.33	0
Project 2	30	18.16	27.43	0.39	0.085
Project 3	18	13.28	17.59	0.26	0.022
Project 4	7.5	5.647	8.52	0.24	0.136
Project 5	4	3.63	5.48	0.0925	0.37
Project 6	8	6.289	9.5	0.21	0.187
Project 7	7.5	3.968	6	0.47	0.2
Project 8	15	13.959	21	0.069	0.4
Project 9	9	7.66	8	0.14	0.11
Project 10	21.5	22.06	23.3	0.026	0.083
Project 11	16.5	11.73	17.71	0.28	0.073

Project	*PM (actual)*	*PM(est)without Ex-Low rating*	*PM(est) with Ex-Low rating*	*MRE without IEM(SCED)*	*MRE with IEM(SCED)*
Project 12	33.75	20.20	30.502	0.401	0.096
Project 13	12	13.20	13.94	0.1	0.161
Project 14	17	13.057	17.29	0.231	0.017
Project 15	31.25	17.24	26.03	0.448	0.167

The median value for MREs, i.e. without IEM(SCED) sorted is calculated as 0.24, and with IEM(SCED) sorted is calculated as 0.11. Prediction level is calculated to find out the proportion of a given level of accuracy.

4.2 Measure prediction level Pred*(l)* for level of accuracy *l*

The prediction level has been calculated on three standard percentages 20, 25 and 30 using Equation 10. In current situation for l = 0.20, k is the number of observations with MRE <= 0.20 and N is the total number of MRE observations. The calculations are shown in Table 10.

Table 10. Pred(l) calculation for MRE without and with IEM(SCED)

MRE Without IEM(SCED)	***MRE with IEM(SCED)***
Pred(0.20)=5/15=0.33	Pred(0.20)=13/15=0.86
Pred(0.25)=8/15=0.53	Pred(0.25)=13/15=0.86
Pred(0.30)=10/15=0.66	Pred(0.30)=13/15=0.86

The derived IEM(SCED) values from Table 10 have been applied into the well-calibrated COCOMOII database and improvement has been observed in the accuracy of the model. This increase in accuracy is shown in Table11.

Table 11. Accuracy Analysis results of COCOMO11

Database		***Pred(20)***	***Pred(25)***	***Pred(30)***
COCOMO II	**Without IEM**	33%	53%	66%
	With IEM	86%	86%	86%

The table shows that by applying the IEM(SCED) values into COCOMOII, all three accuracy levels - Pred(20), Pred(25), and Prec(30) - increase by 53%, 33%, and 20%.

5 Conclusions

The two experiments are performed, one for SCED accuracy analysis and other for deriving new rating level for projects with schedule compression of more than 25%. The result of experiments may lead to following conclusions.

Data reporters often carry out inaccurate subjective judgments for compression level of project schedule, resulting in under estimation of project effort. So it is recommended to choose the exact level of schedule compression level.

The new derived rating level is named extra-low. This level will address projects having compression levels between 25% and 50%. The effort multiplier for this SCED rating is equals to 1.51. This derived rating is applied on the same projects and their effort is re-estimated. The results show improvements in COCOMO II model accuracies, i.e. by 53% for Pred(20), 33% for Pred(25), and 20% for Pred(30).

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