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A FRAMEWORK FOR SOFTWARE PROJECT MANAGERS TO QUANTIFY THE COST EFFECTIVENESS OF EXTREME PROGRAMMING PRACTICES

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EXTREME Programming practices (Xp) is new, innovative and revolutionary software development practices that are being adopted by software companies. Even though the benefits of the Xp are qualitatively discussed, many project managers are reluctant to apply these practices in real projects due to the lack of quantitative proofs. Improvement in productivity of software development is claimed to be one such benefit of the Xp practices. The present research is undertaken to measure the change in software development productivity when the Xp practices are applied. The change in productivity is to be computed by including the other factors that influence productivity. In this paper we propose a framework to measure the effect of extreme programming practices on software development productivity. This framework includes a data analysis and a data collection method. The research model uses multiple linear regression technique as the data analysis method. The above framework was applied and found there is minimum of 25.5 % change in productivity for a change in one level usage of extreme programming practices.

Introduction

The extreme programming (Xp) is a set of lightweight software development processes that is based on four values: Communication, Simplicity Feedback and Courage (Beck, 2000). The four values are achieved with the following highly inter related 12 practices: Onsite customer, small releases, planning game, pair programming, re-factoring, collective code ownership, system metaphor, 40 hours week, coding standards, simple design, continuous integration and continuous testing.

The qualitative discussion on the benefits of extreme programming was dealt in (Beck, 2000). Irrespective of the qualitative explanation on the benefits of extreme programming, many software organizations do not come forward to adopt the extreme programming practices. This is due to the lack of quantitative proofs on the benefits of extreme programming practices. Hence present research was undertaken to quantify the benefits of extreme programming specifically to quantify the effect of extreme programming on software development productivity. It is inherently felt that the Xp practices increase the software development productivity. It was also shown that the pair programming practice alone improves the productivity by 15% (Williams, 2000).

The objectives of our research was to

(i) find whether the use of extreme programming influences software development productivity.

(ii) quantify the change in software development productivity when the use of extreme programming influences the productivity. This change is to be computed concurrently with the changes due to other productivity factors that also influence the software development productivity.

In this paper we propose a frame work to measure the effect of extreme programming practices on software development productivity. The framework includes a data analysis method and data collection method. We have linear multiple regression method for analysis of data and survey method for data collection.

The multiple regression method had been used elsewhere to find the effect of process maturity on software development effort (Clark, 1997) and effect of tools on software development effort (Baik, 2000). By using the multiple regression method we have found the relationship between one of the predictor variable (use of extreme programming practices) and the response variable (development productivity). In the multiple regression model the relationship parameters between response variable and predictor variables are derived empirically from the collected data.

A questionnaire was prepared and the data were collected from the projects which adopted the extreme programming policies. The actual size of the product, development effort and the associated productivity factors were collected. In total 23 productivity factors, 5 COCOMO II scale factors (http://sunset.usc.edu), 17 COCOMO II effort multipliers (http://sunset.usc.edu), and one extreme programming factor were considered for analysis.

The analysis indicates that the use of extreme programming factor does influence the software development productivity. The analysis also indicate that the increase of usage of extreme programming practice of one level will increase the software development productivity a minimum of 25.5 %.

The Section 2 describes the activities in each of the extreme programming practices. It also explains the probable reasons for increase/decrease in productivity for each of the extreme programming (Xp) practice. The research problem, the frame work and the hypothesis testing are explained in section 3. The section 4 describes the data collection method. The result of data analysis is explained in the section 5. A brief conclusion is given in section 6.

Extreme Programming Practices and their Influence

Name and Explanation of the Xp practices.	**Type of influence on the productivity.** **(+) indicates increase of productivity due to the practice.** **(-) reduces the productivity due to the practice.**
1. **Planning game:** The requirements are written as user stories. The effort and risk are estimated for each of the story. The stories for first iteration and release date were planned. The cost implications of using various technology options are analyzed. Roles and team organization are decided. The order of story development within an iteration (doing risky items first can be instigated) are decided. Story cards are prepared and managed. In the case of difficult stories, the spikes are created to understand the potential of the solution. Customer determines the scope (the stories for release and stories for the iteration).The developers estimate effort to develop the stories.	✍ No need of generating time consuming requirement documents. (+) ✍ The accuracy of the estimation of the development effort for user stories is high as the estimation is done by the developers themselves. (+) ✍ The risk analysis is done in the form of pikes. (+). ✍ The user stories are written in front all the developers by a customer. So the requirements are correctly understood in the beginning itself. (+)
2. **Small releases:** Small but frequent releases are happened and feedback is obtained. The obtained feedback is included in its planning for the next release. .A release is a version of a system with enough new features that it can be delivered to users outside the development group. A release may represent one to three months work.	✍ The first iteration of the project may represent the skeleton of the product. Thus the risk analysis is done. (+) ✍ The acceptance test at the end of the each small releases will help to identify the misunderstanding of the requirements at an early stage. (+) ✍ Small releases is a convenient point to introduce the new or change in already implemented requirements. (+)

Name and Explanation of the Xp practices.	Type of influence on the productivity. (+) indicates increase of productivity due to the practice. (-) reduces the productivity due to the practice.
3. **Metaphor:** It is very high level abstraction that represents the working of the system. Example: Postal Mail System, Telephone	✍ Minimum Time is spent on documenting the architecture. (+) ✍ Better understanding of the system for the developers. (+) ✍ Not sufficient, or not really representative metaphors may lead to increase in the effort and thus reduces the productivity. (-) ✍ Not having proper architecture document may become critical in real time and high reliability projects. (-)
4. **Simple Design:** Always use the simplest possible design that gets the job done. The requirements will change tomorrow, so only do what's needed to meet today's requirements.	✍ Minimum effort is spent on design documentation. (+) ✍ Simple design leads to easier implementation. (+) ✍ Simple design leads to less errors so that the lot of effort is saved in defect removal. (+)
5. **Continuous Testing:** Xp teams focus on validation of the software at all times. Programmers develop software by writing tests first (often using automated tools such as JUnit), and then code that fulfills the requirements reflected in the tests. Customers provide acceptance tests that enable them to be certain that the features they need are provided.	✍ The errors are identified early and prevented from propagating to the next level. (+) ✍ The integration is made easier. (+) ✍ The effort for unit test is done. (-)
6. **Refactoring:** The quality of the code is improved, without affecting the functionality of the code, by ensuring the clarity of the code, no duplication, no long classes and the other no bad code smells.	✍ The re-factoring of the code consume considerable effort and consequent testing and integration consumes the development effort. (-) ✍ Increase in the quality of the code leads to decrease in the test effort. (+) ✍ Decreases the complexity of the code leads to effort saving in integration.(+) ✍ During re-factoring the new errors may be injected. Considerable effort is to be spent to remove this defects.(-) ✍ Due to high quality of the refactored code, the code may be reused in the same project itself. (+)
7. **Onsite Customer:** One of the person from the customer organization is s always present with the software development team for the discussions and planning game activities. The customer specify his requirements through a set of simple English sentences called user stories. The customer also writes stories and acceptance tests with the help of development team.	✍ The clarification regarding the requirements can be enquired immediately. (+) ✍ Acceptance tests by the customer during the project period will reveal any misunderstanding of the requirements in the early stage itself. (+). ✍ The onsite customer represents the entire customer organization for finalizing the requirements. The incorrect understanding of the requirements by the onsite customer may lead to decrease in productivity. (-)

Name and Explanation of the Xp practices.	Type of influence on the productivity. (+) indicates increase of productivity due to the practice. (-) reduces the productivity due to the practice.
8. **Pair Programming:** Two persons are allotted at one terminal. Together the pair, design, write test code, code, and re-factor if necessary. Pair programmers are interchanged. The working space for pair programmers are arranged comfortably.	✍ Two programmers doing the same a task reduces the available work force by half. (-). ✍ Productivity increases by 15 %. (+). ✍ Pair rotation may consume some time as the new partner may take time to understand the code.(-) ✍ The increase in quality reduces the test effort. (+) ✍ Due to pair rotation a most of the developers will get to know the code. This helps in code ownership, integration and continuous testing. (+)
9. **Collective Code Ownership:** All the developed code is owned by the entire development team. Any one can improve any part of the code at any time. Every body owns all the code meaning every body is responsible for it. The developers ensure that the unit tests must run before and after each integration.	✍ No time is spent on waiting for the owner of the code to correct if any bug is found out. (+) ✍ When a person corrects the code written by the others, the quality may be improved. (+) ✍ When a person corrects the code written by the others, the errors may be injected. (-) ✍ Some time may be spent in understanding the code written by the others. (-)
10. **40 Hours/week:** The sustainable work hours for company and the developer is decided and strictly followed. i.e. overtime is not allowed.	✍ The developers never get fatigue due to over work. This leads to increase in productivity (more in error finding rate, more code written and less error injection). (+) ✍ Since over time is not allowed the developers may tend to estimate larger amount for implementing the user stories on the safer side. (-)
11. **Coding Standard:** The coding standard is to be defined and every one codes to the same standard. The code itself can serve as a document	✍ Effort is spent in adhering the code requirements. (-) ✍ Adhering the coding standard will reduce effort required for the unit testing, continuous integration and collective code ownership.(+)
12. **Continuous Integration:** Integrate the code several times a day after they get unit tests run for the system to run. Build process is stream lined. One or more machine(s) are reserved for integration.	✍ The integration errors are found at early stage. Thus the propagation of the errors were prevented. (-)

The Research Method

The Research Problem

Whenever a new element such as new tool, new language or process change is introduced in the software development life cycle, usefulness of the newly introduced element is to be found out. The usefulness of the newly introduced element can be found by analyzing the effect of the newly introduced element on some important attributes. The software development productivity is one such attribute. The productivity can be defined in many ways. But for our research the productivity is considered as the ratio between effective source lines of code generated for the product and development effort.

The usefulness of the extreme programming policies can be found out by analyzing the effect of extreme programming policies on software development productivity. The proposed hypothesis is that, increasing the level of usage of extreme programming practices increases the amount of software development productivity. The underlying research problem is to quantify the effect of extreme programming practices on software development productivity when the other productivity factors also affects the productivity. The research problem is to be mapped onto a mathematical model so that the mathematical model can be manipulated to obtain the solution.

Frame Work

The multiple regression analysis is used to analyze the relationship between a single dependent variable and set of predictor variables. For the present research, the response variable is productivity, that is measured as the number source lines generated per programmer month and the predictor variables are the productivity factors including the extreme programming factor. Since the productivity factors are non linearly related to productivity, a non linear multiple regression equation was considered to represent our problem. The power function based (Darper and Smith, 1996) non linear multiple regression equation is selected for our research model. The equation can be given as

$$P = B_0 . X_1^{B1} . X_2^{B2} . X_3^{B3} . \ldots . X_n^{Bn} \quad \text{Equation 1}$$

Where P is the productivity, B_0 is constant, X_1, X_2, X_3, represents some value of the productivity factors of c_1, c_2 c_3 .. Cn respectively. And B_1, B_2, B_3 ... Bn are regression coefficients that represent weight of the productivity factors. Suppose if any productivity factor say X_1's regression coefficient B_1 (weight) is zero, then the productivity factor X_1 does not influence response variable (productivity).

Even though the non linear relationship between productivity and productivity factors is represented by Equation 1, the well established statistical techniques to analyze the data are available only for linear multiple regression models. In order to utilize those statistical techniques, the Equation 1 is converted into linear regression equation by taking logarithm on both sides.

$$\text{Ln}(P) = \text{Ln } B_o + B_1 \text{ Ln } X_1 + B_2 \text{ Ln } X_2 + B_3 \text{ Ln } X_3 + \ldots + Bn \text{ Ln } Xn \ldots \quad \text{Equation 2}$$

The equation 2 is also called as log log linear equation. The 23 productivity factors (5 COCOMO II scale factors, 17 COCOMO II effort multipliers and one extreme programming factor- shown in Table 1) are considered for analysis.

The productivity factors excluding the EXP have been considered for process maturity and proposed three sub models namely full, small, and compact models (Clark, 1997). We have adopted this including extreme programming factor for our analysis as explained below:

The Full Model: In this model all the 23 factors are considered. The equation 2 is rewritten with all 23 productivity factors.

Ln (PRODUCTIVITY) =

$$\begin{aligned}
&\text{Ln}B_0 + B_{PREC} \text{ Ln (PREC)} + B_{RELY} \text{ Ln (RELY)} + B_{DATA} \text{ Ln (DATA)} + \\
&B_{RUSE} \text{ Ln (RUSE)} + B_{TIME} \text{ Ln (TIME)} + B_{STOR} \text{ LN (STOR)} + B_{TEAM} \text{ Ln (TEAM)} \\
&+ B_{ACAP} \text{ Ln(ACAP)} + B_{PCAP} \text{ Ln(PCAP)} + B_{PCON} \text{ Ln (PCON)} + B_{AEXP} \text{ Ln(AEXP)} \\
&+ B_{PEXP} \text{ Ln (PEXP)} + B_{LTEX} \text{ Ln (LTEX)} + B_{FLEX} \text{ Ln (FLEX)} + B_{TOOL} \text{ Ln (TOOL)} + \\
&B_{PVOL} \text{ Ln (PVOL)} + B_{SCED} \text{ Ln (SCED)} + B_{RESL} \text{ LN (RESL)} + B_{PMAT} \text{ Ln (PMAT)} \\
&+ B_{CPLX} \text{ Ln(CPLX)} + B_{EXP} \text{ Ln(EXP)} \ldots \quad \text{Equation 3.0}
\end{aligned}$$

The Small Model: In this model the four high level productivity factors along with the extreme programming factor are considered. The four high level productivity factors are formed by aggregating the associated

Table 1: The Productivity Factors

Sl. No.	Name of the variable.	Explanation of the variable
1	PREC	Precedent ness of the project.
2	RELY	Required reliability for the developed product.
3	DATA	Data handling requirements.
4	RUSE	Reuse level in making the product.
5	DOCU	Level of the documentation required.
6	TIME	Execution time requirements.
7	STOR	Storage requirements.
8	TEAM	Cohesiveness of the Team.
9	ACAP	Analyst capability.
10	PCAP	Programmers' capability.
11	PCON	Personnel continuity.
12	AEXP	Analyst or onsite customer experience.
13	PEXP	Programmers' experience.
14	LTEX	Language and tools experience.
15	FLEX	Development flexibility.
16	TOOL	Usage of CASE Tools.
17	PVOL	Platform volatility.
18	SCED	Schedule pressure.
19	RESL	Architecture resolution.
20	PMAT	Process maturity.
21	SITE	Multi-site development.
22	CPLX	Product complexity.
23	EXP	Level for the use of extreme programming.

productivity factors as in Table 2. For aggregation the multiplication of associated productivity factors are employed. The small model equation is given below.

$\text{Ln (PRODUCTIVITY)} = \text{Ln} (B_0) + B_{\text{PRODUCT}} \text{ Ln (PRODUCT)} + B_{\text{DEVT}} \text{ Ln (DEVT)} + B_{\text{PROCESS}} \text{ Ln (PROCESS)} + {} + B_{\text{ENVN}} \text{ Ln (ENVN)} + B_{\text{EXP}} \text{ Ln (EXP)}$ ….. Equation 4.0

Table 2: The aggregated variables

Sl.No	Name of the Group	Aggregated variable Name	Aggregation of the productivity factors
1.	Product related productivity factors.	PRODUCT	PREC, RESL, RELY, DATA, CPLX, RUSE, DOCU, TIME, and STOR
2.	Development Team productivity factors.	DEVT	ACAP, PCAP, AEXP, PEXP, LTEX, PCON, TEAM
3.	Process Related productivity factors.	PROCESS	PMAT
4.	Environment related cost factor	ENVN	FLEX, TOOL, SITE, PVOL, SCED
5.	Extreme programming related cost factor.	EXP	EXP

Compact Model: In this model only two predictor variables are considered.

$$\text{Ln (PRODUCTIVITY)} = \text{Ln } B_0 + B_{EM} \text{ Ln (EM)} + B_{EXP} \text{ Ln (EXP)} \ldots \ldots\ldots\ldots \text{Equation 5.0}$$

Where the variable EM represents the aggregation of all the 22 COCOMO productivity factors of Table 1.

Hypothesis Testing

The aim of the present research is to compute the value of B_{EXP} (regression coefficient of EXP predictor) from collected software development project data and to prove that B_{EXP}!=0. If the B_{EXP} is zero, it implies that the use of extreme programming factor does not affect the productivity. Because substituting the B_{EXP} that is zero in the research model (Equation. 1) will make the EXP, related term one. The null hypothesis and the alternative hypothesis are stated as follows:

H0:B_{EXP} =0

H1:B_{EXP} !=0

The null hypothesis is to be tested at 95% confidence level (Darper and Smith, 1996).

Computation of the Regression Coefficient B_{EXP}: It is possible to compute B_{EXP} only when the data for the entire population (considering all the software development projects which use extreme programming approach) is available. Even though, theoretically it is possible to compute the B_{EXP}, in reality it is only possible to compute the b_{EXP} (from samples) which is an estimate of B_{EXP}. But given a b_{EXP}, it is possible to find the interval (range) in which the B_{EXP} value will lie. The interval is called b_{EXP} estimation interval. In order to successfully conclude that the EXP does affect the productivity, the zero value should not exist in b_{EXP} interval.

Data Collection Method

We have adopted the survey method to collect the data. The data were obtained by obtaining responses for a questionnaire (www.vsnl.net). The questionnaire is adopted from (http://sunset.usc.edu). The development effort and size of the project were the only quantitative data obtained. The qualitative data is obtained for all the other productivity factors. The data were collected from 21 projects. Out which 16 project data were considered for the data analysis and the others were rejected due to the presence of the outlier values. The only small and compact research model is used for data analysis.

Computation of Software Development Productivity

The productivity is computed as the ratio between Effective Source Lines of Code and Effort in Person Months. A person month is defined as 152 man hours. The Effective Source Lines of Code (ESLOC)is computed as follows.

$$\text{ESLOC} = \text{NSLOC}*((\text{BRAK}+100)/100)+(\text{ASLOC}*.20)$$

Where

NSLOC - Newly Generated Source Lines of Code

ASLOC - Adopted Source Lines of Code (from other projects or from library)

Break - The percentage of code thrown away due to the change in requirements.

COCOMO Productivity Factors

Ratings and Values: The ratings for the COCOMO II productivity factors (5 scale factors and 22 effort multipliers) are obtained in the interval scale, having the following ratings: VERY LOW, LOW, MEDIUM, HIGH VERY HIGH, and EXTRA HIGH.

Assigning Numerical Values to COCOMO Predictors: In order to do the analysis the qualitative predictor values, are to be converted into numerical values. As a first step the ratings for COCOMO predictors VERY LOW. LOW, MEDIUM, HIGH, VERY HIGH, and EXTRA HIGH are converted into R1, R2, R3, R4, R5, and R6. The frequency response for the each of the predictor value determines the median of the predictor values. Median ratings were given a value of 1.0. The ratings on either side of the median were given values that differs from 1.0 by 10%. For example, in a project if the ratings of PREC predictor changes from R3 to R4 the productivity will increase by 10%. For brevity, assigned values are shown only for three COCOMO predictors in Table 3.

Table 3: Assignment of Numerical Values to COCOMO Predictors

Predictor	R1	R2	R3	R4	R5	R6	PR
PREC	1.10	1	0.9	0.81	0.729	0.6561	1.6
RELY	0.73	0.81	0.9	1	1.1	-	1.5
DATA	-	0.81	0.9	1	1.1	-	1.3

The Productivity Range(PR) gives the ratio between highest predicator value and the lowest predictor value. For example if the predictor value for DATA changes from R2 to R6, there occurs 30% productivity difference.

Extreme Programming Factor

Each of the twelve Xp practices are measured using a nominal scale. The ratings, description of the ratings and the weights assigned to each of the ratings are explained in Table 4. The value for extreme programming factor (EXP) is obtained by computing weighted average of all 12 policies. The 12 policies are given equal weightage.

Table 4: EXP Measurement Scale

Sl.No.	Ratings	Description of the Ratings	Weight
1	Almost always	(over 90% of the time) When the practice is adopted as recommended.	100
2	Frequently	(about 60 to 90% of the time) When the practice are is adopted but some times the practice is omitted due to difficult circumstances.	75
3	About Half	(about 40 to60% of the time) When the practice is about half of the time.	50
4	Occasionally	(about 10 to 40% of the time) When the practice is followed but less often.	25
5	Rarely if ever	(less than 10% of the time) When the practice is rarely followed.	1
6	Not followed	When the practice is not followed at all.	0
7	Don’t know	When you are uncertain about how to respond for the particular practice.	0

The final rating EXP is computed as the weighted average of all 12 practices as below.

$$\boxed{\text{Weight of } X_{Pi}\% \quad =} \qquad \text{..} \text{ ………….Equation 6.0}$$

Assigning Numerical Value to EXP: The numerical value for the EXP for each of the project predictor is obtained through equation 6.0. EXP can have values from 0 to 5.0.. The median value of the EXP data is found to be 3.86 (average of 8th and 9th project EXP values, when they are arranged in ascending order) and is assigned with rating of 1.0. The EXP values which differ the median value by 1 are given 10% increase or decrease in value on either side. This is shown in Table 5. The value for all other Xp projects were interpolated by using the values given in Table 5. The computed EXP values and the assigned EXP values are given in Table 6.

Table 5: Interval Range of EXP values

EXP Values	4.86	3.86	2.86	1.86	.86
Assigned Value	1.1	1.0	0.9	0.81	0.729

Table 6: The Computed and Assigned Values for EXP

EXP Collected	2.92	3.75	2.92	2.08	2.41	3.34	4.27	4.06	3.75	4.79	3.96	3.75	4.17	4.27	4.69	4.38
EXP Assigned	.96	.99	.91	.83	.86	.95	1.04	1.02	.99	1.09	1.01	.99	1.03	1.04	1.08	1.05

Results and Discussion

The data collected for 16 Xp projects were analyzed using small and compact models. The results are shown in Table 7.

Table 7: Results

Model	**Fitness of the model**				**(b_{EXP}):- Reg. Coefficient.**	**t-value**	**b_{EXP} interval**
	R^2	**Adj R^2 0.72**	**Std. Err.**	**p Value of A-Table**			
Small Model	0.92	0.88	0.0893	0.00	3.08	8.06	2.23 to 3.93
Compact Model	0.88	0.86	0.097	0.00	3.30	9.58	2.55 to 4.05

Model Fitness: It can be seen from the table that both models' R^2 and Adj R^2 are more than 86%. Thus variation in the response variable is accounted by more than 86% of the variation in the response variable. Thus the model fits well.

Since the p value of the ANOVA table is less than 0.01 for both models, there is a statistically significant relationship between the variables at the 99% confidence level.

Results of Hypothesis Testing: The regression coefficients (bEXP) for the small and compact models are 3.08 and 3.30 respectively. The interval estimation of bEXP for Compact Model and Small Model are 2.23.to 3.93 and 2.55 to 4.05 respectively. Thus the B_{EXP} value is not zero in the point estimation as well as B_{EXP} can not have zero value in the estimation interval. Thus the Null Hypothesis is rejected and alternate hypothesis(use of extreme programming policies affect the software development productivity) is accepted. As t value in the table for both the models are more than 1.76 the null hypothesis is rejected with 95% confidence level.

Quantification: 2.55 to 3.93 is a common range in estimation intervals of regression coefficient of both models. Considering the minimum value of this common range there will be 25.5 % improvement in the productivity for one level increase of usage of extreme programming practices.

Conclusion

We have proposed a framework to measure the effects of extreme programming practices on software productivity. The framework contains a data analysis method and data collection method. The framework was applied to collect data and analyze. The results indicate that the use of Extreme Programming Practice is a significant factor affecting the software development productivity. At one level change in the level of usage of extreme programming practice increases the productivity by 25.5 %. We hope this finding will help the managers to take decision to adopt extreme programming for the software development.

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