A Literature Survey on the Accuracy of Software Effort Estimation Models

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***Abstract*— Accurate software effort estimation is crucial for the software development process. Neither over estimated nor underestimated effort is welcome. Academic researchers and practitioners have long been searching for more accurate estimation models or methods. The objective of this paper is to explore the studies on software effort estimation accuracy available in the literature and analyze the findings to obtain the answer for the question: which software effort estimation model is more accurate? There were very limited reports that satisfied the research criteria. Only 8 studies with 10 reports were discovered for the analysis. It is found that Use Case Point Analysis outperforms other models with the least weighted average Mean Magnitude of Relative Error (MMRE) of 39.11%, compare to 90.38% for Function Point Analysis and 284.61% for COCOMO model. It indicates that there is still need to improve the estimation performance but the question is how.**

***Index Terms*—software effort estimation, performance of software effort estimation models, Function Point Analysis, Use Case Point Analysis, COCOMO models.**

I. Introduction

Accurate software cost estimation is crucial for the software development process. It is used for project planning and control purposes during the project execution [1]. Either over estimated or underestimated cost is not welcome.

Academic researchers and practitioners have long been searching for more accurate estimation models or methods. In 1987, Kemerer in [2] posed two research questions: a) are models that do not use source lines of code as accurate as those do? And b) are the models available in the open literature as accurate as proprietary models? Empirical data were gather to compare the performance of the four software cost estimation models: SLIM, COCOMO models, ESTIMAC and Function Points. However, the results were inconclusive.

Over the years of development, have we achieved the answer for the question: which software effort estimation model is more accurate? The objective of this paper is therefore to explore the studies on software estimation accuracy available in the literature and analyze the findings to obtain the answer for this question.

This article is organized as follows. Section II gives the review on how the software estimation accuracy was measured and the research method employed is given in Section III. Section IV presents the findings. Finally, section V concludes and discusses the future research.

II. Estimation Accuracy Evaluation Criteria

The Magnitude of Relative Error (MRE) and the Mean Magnitude of Relative Error (MMRE) [3], [4] are used to evaluate the accuracy of the cost estimation models. They are defined as:

$$MRE = \left|\frac{y_i - \hat{y_i}}{y_i}\right|$$

Where y_i is the actual value and $\hat{y_i}$ is the estimate

$$MMRE = \frac{1}{n}\,x\sum_{i=1}^{n} MRE_i$$

Where n is the number of estimates; and MRE_i is the Magnitude of Relative Error (MRE) of the i^{th} estimate.

III. Research method employed

The objective of this paper is to explore the studies on software estimation accuracy available in the literature and analyze the findings to obtain the answer for the research question. However, over the years, there have been a lot of researches contributed to software effort estimation models. There are many recognized software estimation models or methods. This paper thus proposed to study 3 prominent estimation models: Function Point Analysis, Use Case Point Analysis, and COCOMO Model since they are more well-known and recognized [2], [5], [6]. Because otherwise it may result in there is no report needed available in the literature had the less well-known or recognized models were selected.

In order to answer the research question, another criteria is that the studies included should report both software estimated effort and software actual effort, or Magnitude of Relative Error (MRE) so that it is possible for the analysis to answer the research question. There are altogether 8 studies with 10 reports that satisfied the information needed -- 3 of Function Point Analysis, 4 of Use Case Point analysis and 4 of COCOMO model.

IV. Findings

The studies of the software estimation accuracy reviewed are listed in table I, in estimation model and chronological order.

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A. *Function Point Analysis Results*

Table I shows that there are only 3 studies of accuracy Function Point Analysis found that contented the information needed. They are the studies of Kemerer [2] in 1987, Chandrasekaran and Kumar [7] in 2012, and Arnuphaptrairong [8] in 2013. In fact, there are many other studies in the literature but most of them are about Project Delivery Rates: PDR or Productivity rates which did not satisfy the research criteria.

TABLE I
STUDY REPORT REVIEWED

No.	Estimation Model	Author	Year	Number of Software Projects
1	FPA	Kemerer	1987	15
2	FPA	Chandrasekaran and Kumar	2012	13
3	FPA	Arnuphaptrairong	2013	1
4	UCP	Gencel *et al.*	2000	1
5	UCP	Anda *et al.*	2001	3
6	UCP	Caroll	2005	1
7	UCP	Frohnhoft and Engels	2008	15
8	COCOMO	MayaZaki and Mori	1985	33
9	COCOMO	Kemerer	1987	15
10	COCOMO	Chandrasekaran and Kumar	2012	1

Kemerer [2]

In 1987 Kemerer [2], in the paper entitled “An Empirical Validation of Software Cost Estimation Models” compared the accuracy of 4 estimation models: FPA, COCOMO, SLIM, and ESTIMACS. Table II shows the effort estimate (man-month), the actual effort (man-month), and percentage MRE data of the 15 software projects using Function Point Analysis (FPA) for the effort estimation.

TABLE II
DETALIS OF THE SOFTWARE PROJECTS FROM
KEMERER [2]

Project	Estimated Effort (man –month)	Actual effort (man –month)	MRE (%)
1	344.30	287.00	19.97
2	92.13	82.50	11.67
3	731.43	1,107.30	33.94
4	192.03	86.90	120.98
5	387.11	336.30	15.11
6	61.58	84.00	26.69
7	52.60	23.20	326.73
8	264.68	130.30	103.13
9	477.81	116.00	311.91
10	2.83	72.00	103.93
11	484.24	258.70	87.18
12	192.21	230.70	16.68
13	157.36	157.00	0.23
14	390.63	246.90	58.21
15	282.91	69.90	304.74
		MMRE (%)	**102.74**

Table II shows the data set of FPA --the effort estimates and the actual effort in man month. All of the data of the 15 software projects were collected from one company. The software project sizes range from 39 KSLOC to 200 KSLOC. Most of them are COBOL business applications. The percentage of Mean Magnitude of Relative Error (MMRE) is 102.74.

Chandrasekaran and Kumar [7]

Chandrasekaran and Kumar [7], in the article entitled “on the Estimation of the Software Effort and Schedule using Constructive Cost Model –II and Function Point Analysis” in 2012, described a case study applying COCOMO model and Function Point Analysis for the effort estimation. Table III shows data of the case study using Function Point Analysis for the effort estimation --the effort estimate (34.30 man-month), the actual effort (30.12 man-month), and percentage MRE (13.8%).

TABLE III
DETALIS OF THE SOFTWARE PROJECT FROM
CHANDRASEKARAN AND KUMAR [7]

Estimated Effort (Man-Month)	Actual Effort (Man-Month)	MRE (%)
34.30	30.12	13.8

Arnuphaptrairong [8]

In 2013, Arnuphaptrairong [8] reported in the paper entitled “Early Stage Software Effort Estimation Using Function Point Analysis: An Empirical Validation.” The paper reported the accuracy of Function Point Analysis of 13 software projects using data available in the dataflow diagram. Table IV shows the effort estimates (man-hour), the actual efforts (man-hour), and percentage MRE from the analysis.

TABLE IV
DETALIS OF THE SOFTWARE PROJECTS FROM
ARNUPHAPTRAIRONG [8]

Project No.	Estimated Effort (man –hour)	Actual effort (man –hour)	MRE (%)
1	4,959.33	400.00	1,139.83
2	6,613.23	1,016.00	550.91
3	34,721.80	560.00	6,100.32
4	1,830.98	640.00	186.09
5	2,461.02	240.00	925.43
6	1,416.48	400.00	254.12
7	6,147.94	458.00	1,242.34
8	4,432.44	384.00	1,054.28
9	1,211.29	550.00	120.23
10	1,188.59	600.00	98.10
11	3,027.70	520.00	482.25
12	3,635.39	1,080.00	236.61
13	8,384.19	95.00	8,725.46
		MMRE (%)	**1,624.31**

The 13 projects were student projects required for their master program. All of them were business application implemented with VB.net, C++, or C#.net. The Mean Magnitude of Relative Error (MMRE) was 1,624.31% which was very high. All the estimated values were higher the actual efforts for every projects.

The author explained that it could be because of not using the appropriate Project Delivery Rates (PDR). The author had tried various Project Delivery Rates available in the literature. The results are shown in table V.

TABLE V
THE MAGNITUDE OF RELATIVE ERROR (MRE) WITH VARIOUS PROJECT DELIVERY RATES

Author (year)	Effort (man-hour)	MRE (%)
Albretch & Gaffney (1983) [9]	Effort = FP / 0.0595 or 16.81 *FP	1,747
Behrens (1983) [10]	Effort = 18.3 * FP	1,894
Moser & Nierstrasz (1996) [11]	Effort = 6.667 * FP	629
Lokan et al. (2000) [12]	Effort = 21 * FP $^{(0.826)}$	82
Maxwell&Forselius (2000) [13]	Effort = FP / 0.337 or 2.97 * FP	263
Jeffery et al. (2001) [3]	Effort = 2.2 * FP	189

Table V shows that the selection of Project Delivery Rates or project delivery rate (PDR) can produce better results. For example, with the productivity rate equation of Lokan *et al.* (2000) -- Effort = 21 * FP (0.826), gives a MMRE of 82%, or with the productivity rate of Jeffery et al. (2000) -- Effort = 2.2 * FP, resulted in a MMRE of 189%.

Table VI summarized the accuracy of the three studies. The weighted average MMRE of all studies is 90.38%.

TABLE VI
PERCENTAGE OF MMRE OF ALL THREE FUNCTION POINTS STUDIES

Report no.	Author (Year)	Number of software Projects	MMRE (%)
1	Kemerer (1987)	15	102.74
2	Chandrasekaran and Kumar (2012)	1	13.8
3	Arnuphaptrairong (2013)	13	82.00
		Weighted average of all reports	90.38

B. *Use Case Point Analysis Results*

From the review of literature, there are four reports on the accuracy of Use Case Point (UCP) Analysis that contain the data needed. They are Gencel *et.al.* [14] in 2000, Anda *et.al.* [6] in 2001, Caroll [15] in 2005 and Frohnhoft and Engels [5] in 2008. The following section gives the details of these reports.

Gencel *et.al.* [14]

Gencel *et.al.* [14], in the article entitled “A Case Study on the Evaluation of COSMIC-FFP and Use Case Points” in 2000, presented the results of a case study on applying COSMIC-FFP and Use Case Point methods to a military inventory management software that integrated with a document management system project. Table VII shows the effort estimate (11,859.88 man-hour), the actual effort (6,308 man-hour), and percentage MRE (88.01%) data of the case study.

TABLE VII
DETALIS OF THE SOFTWARE PROJECTS FROM GENCEL *ET AL.* [14]

Estimated effort (Man-Hour)	Actual effort (Man-Hour)	MRE (%)
11,859.88	6,308	88.01

Anda *et.al.* [6]

Anda *et.al.* [6], in the article entitled “Estimating Software Development Effort based on Use Case – Experience from Industry”, in 2001, reported the experience in applying Use Case Point method for three industrial case studies of a Scandinavian software company. Table VIII shows the effort estimate (man-day), the actual effort (man-day), and percentage MRE data of the three case studies. The MMRE of the three projects was 27.30%.

TABLE VIII
DETALIS OF THE SOFTWARE PROJECTS FROM ANDA *ET AL.* [6]

Case	Estimated Effort (Man-Hour)	Actual effort (Man-Hour)	MRE (%)
1	3,670	2,550	30.52
2	2,860	3,320	16.08
3	2,740	2,080	24.09
		MMRE	27.30

Caroll [15]

Caroll [15] in the article entitled “Estimating Software Based on Use Case Points” in 2005, described how a large software company -- Agilis Solutions in Oregon, estimates software project cost using Use Case Point Analysis. The article showed how to use and suggest improvement through a case study. Table IX shows the effort estimate (420 man-day), the actual effort (245.98 man-day), and percentage MRE (70.75) data of the case study.

TABLE IX
DETALIS OF THE SOFTWARE PROJECTS FROM CAROLL [15]

Effort estimate (Man-Day)	Actual effort (Man-Day)	MRE (%)
420	245.98	70.75

Frohnhoft and Engels [5]

In presenting a method to improve Use Case Point Analysis, Frohnhoft and Engels [5], in 2008, applying Use Case Point method on 15 commercial software projects in a company --sd&m, in Capgemini. Table X shows the effort estimate (man-hour), the actual effort (man-hour), and percentage MRE data of the 15 projects.

TABLE X
DETALIS OF THE 15 SOFTWARE PROJECTS FROM FROHNHOFT AND ENGELS [5]

Project	Industry	Effort estimates (Man- Hour)	Actual Effort (Man-month)	MRE (%)
1	Apparel industry	1,205	728	65.52
2	Automotive	11,667	15,500	24.73
3	Automotive	114,023	136,320	16.36
4	Finance	1,002	2,992	66.51
5	Finance	3,301	3,680	10.30
6	Insurance	2,115	4,800	55.94
7	Logistics	1,406	944	48.94
8	Logistics	1,751	2,567	31.79
9	Logistics	8,840	7,250	21.93
10	Logistics	52,219	61,172	14.64
11	Public	39,030	46,900	16.78
12	Public	19,442	13,200	47.29
13	Telco	3,588	2,456	46.09
14	Telco	3,186	2,432	31.00
15	Telco	1,518	1,056	43.75
			MMRE	36.10

Table XI summarized the accuracy of the four studies. The weighted average MMRE of all studies was 39.11%.

TABLE XI
PERCENTAGE OF MMRE OF ALL FOUR USE CASE POINT STUDIES

No.	Author (Year)	Number of software projects	MMRE (%)
1	Gencel et.al. (2000)	1	88.01
2	Anda et.al. (2001)	3	27.30
3	Caroll (2005)	1	70.75
4	Frohnhoft and Engels (2008)	15	36.10
		Weighted average MRE	39.11

C. *COCOMO Model Results*

There are not many reports about CCOCOO model accuracy. Three reports of COCOMO model accuracy were found in the review of literature that contented the information needed. They are the studies of MayaZaki and Mori in 1985 [16], Kemerer in 1987 [2], and Chandrasekaran and Kumar in 2012 [7].

MayaZaki and Mori [16]

In 1985, MayaZaki and Mori [16], in the article entitled "COCOMO Evaluation and Tailoring", reported the accuracy of applying COCOMO model in the study of 33 software projects. The MRE was found at 165.6%. The details of the project effort estimates and actual efforts were not shown in the report.

Kemerer [2]

In 1987, Kemerer [2], as mentioned earlier, in his paper entitled "An Empirical Validation of Software Cost Estimation Models" besides reported the accuracy of Function Point Analysis, also reported the accuracy of the COCOMO Model that performed on 15 software projects of a software company. The software were mostly business application written in COBOL ranged from 39 KSLOC to 200 KSLOC. Kemerer analyzed many COCOMO models. COCOMO Intermediate showed the least Mean Magnitude of Relative Error (MMRE). The effort estimate (person month), the actual effort (person month), and percentage MRE of the 15 software projects are shown in Table XII. The Mean Magnitude of Relative Error (MMRE) of the 15 projects was 583.82%

TABLE XII
DETALIS OF THE SOFTWARE PROJECTS FROM KEMERER [2]

No.	Estimated Effort (person month)	Actual Effort (person month)	MRE (%)
1	917.56	287.00	219.71
2	151.66	82.50	83.83
3	6,182.65	1,107.30	458.35
4	558.98	86.90	543.25
5	1,344.20	336.30	299.70
6	313.36	84.00	273.05
7	234.78	23.20	911.98
8	1,165.70	130.30	794.63
9	4,248.73	116.00	3,562.70
10	180.29	72.00	150.40
11	1,520.04	258.70	487.57
12	558.12	230.70	141.82
13	1,073.47	157.00	583.74
14	629.22	246.90	154.85
15	133.94	69.90	91.62
		MMRE	583.82

Chandrasekaran and Kumar [7]

In 2012, Chandrasekaran and Kumar [7], in the article mentioned earlier, reported a case study applying both COCOMO model and Function Point Analysis for the software project effort estimation. Table XIII shows the effort estimate (32.66 man-month), the actual effort (30.12 man-month), and percentage MRE (8.4%) data of the case study for the COCOMO model estimation.

TABLE XIII
DETALIS OF THE SOFTWARE PROJECT FROM CHANDRASEKARAN AND KUMAR [7]

Estimated Effort (Man-Month)	Actual effort (Man-Month)	MRE (%)
32.66	30.12	8.4

Table XIV summarized the accuracy of the four studies. The weighted average MMRE of all studies was 284.61%.

TABLE XIV
PERCENTAGE OF MMRE OF ALL THREE COCOMO STUDIES

No.	Author (Year)	Number Software project	MMRE (%)
1	MayaZaki and Mori (1985)	33	165.60
2	Kemerer (1987)	15	583.82
3	Chandrasekaran and Kumar (2012)	1	8.4
		Weighted Average MMRE	284.61

V. Conclusions, Discussions and Future Research

There were very limited reports that satisfied the research criteria. Only 8 studies with 10 reports were found for the analysis. Table XV concluded the accuracy performance of the 10 reports presented above –3 of Function Point Analysis, 4 of Use Case Point Analysis and 3 COCOMO Model.

Table XV illustrates that Use Case Point Analysis outperforms other models with the least weighted average Mean Magnitude of Relative Error (MMRE) of 39.11%, compare to 90.38% for Function Point Analysis and 284.61% for COCOMO model.

TABLE XV
PERCENTAGE OF WEIGHTED AVERAGE MMRE OF ALL THREE ESTIMATION MODEL

Estimation Model	Number of study	Author	Weighted Average MMRE (%)
Function Point Analysis	3	Kemerer (1987), Arnuphaptrairong (2013), Chandrasekaran and Kumar (2012)	90.38
Use Case Point Analysis	4	Gencel et.al. (2000), Anda et.al. (2001), Caroll (2005) Frohnhoft and Engels (2008)	39.11
COCOMO Model	3	MayaZaki and Mori (1985) Kemerer (1987) Chandrasekaran and Kumar (2012)	284.61

Table XV shows that the MMRE of the three estimation models are still very high [17], [18]. The lowest is the Use Case Point Analysis with MMRE of 39.11%. Then the question is: what are the causes of inaccuracy of software estimates?

Lederer and Prasad [17] reviewed from the literature 24 causes of estimate inaccuracy. They surveyed 400 information system managers and analysts to collect their opinions on these 24 causes of inaccurate and 116 returned. The respondents were asked to rate using the 5 point Likert-scale which each was responsible for the inaccurate. Table XVI shows the top ten causes indicated by the respondents.

Additional analysis was performed to find correlation between causes and inaccuracy. Table XVII shows top ten causes which statistically significant correlated with inaccuracy.

TABLE XVI
TOP TEN CAUSES OF INACCURACY ESTIMATES (LEDERE AND PRASAD [17])

No.	Causes of Inaccuracy	Mean
1	Frequent requests for changes by users	3.89
2	Users' lack of understanding of their own requirements	3.60
3	Overlooked tasks	3.59
4	Insufficient user-analyst communication and understanding	3.34
5	Poor or imprecise problem definition	3.29
6	Insufficient analysis when developing estimate	3.21
7	Lack of an adequate methodology or guidelines for estimating	3.09
8	Lack of coordination of systems development, technical services, operations, data administration, etc., functions during development	3.06
9	Changes in Information Systems department personnel	2.59
10	Insufficient time for testing	2.86

TABLE XVII
TOP TEN CAUSES CORRELATED WITH INACCURACY (LEDERE AND PRASAD [17])

No.	Causes	Correlation
1	Performance reviews don't consider whether estimate were met	0.45*
2	Lack of setting and review of standard duration for use in estimating	0.36*
3	Lack of project control comparing estimates and actual performance	0.33*
4	Lack of careful examination of the estimate by Information systems Department management	0.30*
5	Reduction of project scope or quality to stay within estimate, resulting in extra work later	0.25*
6	Red tape	0.23*
7	Lack of diligence by system analysts and programmers	0.23*
8	Lack of an adequate methodology or guideline for estimating	0.22*
9	Poor or imprecise problem definition	0.22*
10	Overlooked tasks	0.20*

* Statistical significant

Factor analysis was also performed and found that the 24 factors can be grouped into 4 groups or factors namely, --Methodology, Management control, Politics and User communication. They explained, as indicated in table XVI, that the information manager pointed to user communication factor (Users' lack of understanding of their own requirements, Frequent requests for changes by users, Users' lack of data processing understanding, poor or imprecise problem definition) while as indicated in table XVII the factor that are correlated to the inaccurate are in fact the management control factor (i.e. Performance reviews do not consider whether estimates were met, Lack of project control comparing estimates and actual performance, and lack of careful examination of the estimate by Information Systems Department control).

Of the observation that Use Case Point Analysis outperforms other models with the least weighted average Mean Magnitude of Relative Error (MMRE) of 39.11%, and the MMRE of the three estimation models are still very high [17], [18]. It indicates that there is still need to improve the estimation performance but the question is how to improve. One of the proposition is to incorporate the causes of software estimation inaccuracy of software estimates reviewed from [17] into the software estimation models. But again it leaves another question on how to integrate these factors into the estimation models or method for the future research.

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