Software Effort Estimation Using Fuzzy Logic: A Review

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Abstract

One of the major problems with software project management is the difficulty to predict accurately the required effort for developing software applications. This is due to the reason that most of the software estimates should be performed at the beginning of the life cycle, when we do not yet know the problem we are going to solve. The task of effort estimation is challenging and is an important area of research in the field of Software Project Management. Though a number of estimation models exist for effort prediction, still many newer models are being proposed and active research is going on to obtain more accurate estimation models. In this paper we survey the most common and widely used effort estimation techniques using fuzzy logic. The survey shows that fuzzy logic effort estimation can be coupled with other techniques such as neural network, Bayesian Network and Particle Swarm Optimization technique. Recent trends on effort estimation have also been discussed at length.

Keywords- *Software Development Effort, Effort Estimation, Fuzzy Logic Techniques, Estimation Models.*

1. Introduction

It is ideally desirable that the improvement in estimation techniques currently available to project managers would facilitate increased control of time and overall cost benefit in software development life cycle. Furthermore, any improvement in the accuracy of predicting the development effort can significantly reduce the costs from errors, such as estimating inaccurately, inappropriate tendering bids, and disabling the monitoring progress. Software development effort estimates are the basis for project bidding and planning. The consequences of poor budgeting and planning can be disastrous: if they are too pessimistic, business opportunities can be gone astray, while optimism may be followed by significant loss. Software effort estimation has even been identified as one of the three most demanding challenges in software application areas [1]. During the development process, the cost and time estimates are useful for the initial rough validation and monitoring of the project‘s completion process. And in addition, these estimates may be useful for project productivity assessment phases. Software effort estimation models are divided into two main categories: viz., algorithmic and non-algorithmic. The most popular algorithmic estimation models include Boehm‘s COCOMO [2], Putnam‘s SLIM[3] and Albrecht‘s Function Point[4]. Non-algorithmic techniques include Price-to-Win [1],Parkinson [1], expert judgment [1] and machine learning approaches[5]. Machine learning is used to group together a set of techniques that embodies some of the facets of human mind [5]. For example, fuzzy systems, analogy, regression trees, rule induction and neural networks are among the machine learning approaches, and fuzzy systems and neural networks are considered to belong to the soft computing paradigm.

1.1 Algorithmic models

Some of the famous algorithmic models are: Boehm’s COCOMO’81, II (Boehm *et al*., 2000), Albrecht’s Function Point (Boehm *et al*., 2000; Boehm, 1995) and Putnam’s (1978) SLIM. All of them require inputs, accurate estimate of specific attributes, such as Line of Code (LOC), number of user screen, interfaces and complexity, which are not easy to acquire during

the early stage of software development life cycle process. Models based on historical data have limitations. Understanding and the calculation using these models are difficult due to inherent complex relationships between the related attributes, which are unable to handle categorical data as well as lack of reasoning capabilities [6]. Besides, attributes and relationships used to predict software development effort those could change with the passage of time and/or differ for software development environments (Srinivasan and Fisher, 1995). The limitations of the algorithmic models led to the exploration of the nonalgorithmic techniques visualised through soft computing philosophy.

1.2 Non-Algorithmic models

In 1990's non-algorithmic model was conceptualized and have been proposed to project cost estimation. Software researchers have turned their attention to new approaches those are based on soft computing methodologies such as based on artificial neural networks and fuzzy logic models and genetic algorithms based implementations. Neural networks are able to generalize from trained data set. A set of training data, a specific learning algorithm makes a set of rules that fit the data and fits previously unseen data in a rational manner as well. Some of the early works show that neural networks are adequately applicable to cost estimation phases as presented in the works of Venkatachalam [7] and Krishna and Satsangi [8]. Fuzzy logic offers a powerful linguistic representation that is sufficiently accommodate the imprecision in inputs and outputs, while providing a more realistic knowledge based approach to model building. Contemporary research establishes to some extent that fuzzy logic model achieved good performance index, being outperformed in terms of accuracy only by neural network model with considerably more input variables. Hodgkinson and Garratt in their works presented that estimation by expert judgment was better than all regression based models [9].

1.3 Fuzzy logic models

A fuzzy model is used when the systems are not suitable for analysis by conventional approach or when the available data is uncertain, inaccurate or vague [10]. The fuzzy model uses the fuzzy logic concepts introduced by Lofti A. Zadeh [11]. Fuzzy reasoning consists of three main components [12]: fuzzification process, inference from fuzzy rules and defuzzification process. Fuzzification process is where the objective term is transformed into a fuzzy concept. The membership functions are applied to the actual values of variables to determine the confidence factor or membership value (MV). Fuzzification allows input and output to be expressed in linguistic terms. Inferencing involves defuzzification of the conditions of the rules and propagation of the confidence factors of the conditions to the conclusion of the rules. Defuzzification process refers to the translation of fuzzy output into objective terms.

A system based on Fuzzy Logic has a direct relationship with fuzzy concepts (such as fuzzy sets, linguistic Variables etc.) and fuzzy logic. The popular fuzzy logic systems can be categorised into three types: pure fuzzy logic systems, Takagi and Sugeno's fuzzy system, fuzzy logic systems with fuzzification and defuzzification [12]. Since most of the engineering applications produce crisp data as input and expects crisp data as output, the last type i.e., fuzzy logic system with fuzzification and defuzzification is most widely used one and was first proposed by Mamdani. It has been successfully applied to a variety of industrial processes and consumer products [12].

1.3.1 Fuzzy Logic in Software Effort Estimation

A fuzzy set theoretic model is a modelling construct featuring two main properties [13]: (1) It operates at a level of linguistic terms (fuzzy sets), and (2) it represents and processes uncertainty. Fuzzy logic offers a particularly convenient way to generate a keen mapping between input and output spaces thanks to the natural expression of fuzzy rules. In software development effort estimation, two considerations justify the decision of implement--ing a fuzzy model:1) it is impossible to develop a precise mathematical model of the domain [14]; second, metrics only produce estimations of the real complexity. Thus, according to the previous assertions, formulating a tiny set of natural rules describing underlying interactions between the software metrics and the effort estimation could effortlessly reveal their intrinsic and wider correlations.

2. Review of Software Estimation Based On Fuzzy Logic Techniques

During the last decade, many methodologies have been developed in the areas of software cost estimation for improving estimation accuracy. Here we present a tabular view (Table 1) of works of various authors on software development effort estimation based on Fuzzy Logic techniques and concepts.

Table 1. Research on Software Development Effort Estimation Based On Fuzzy Logic Techniques.

Authors	Year	Related Work Done	Result Reported
Fei Z and Liu X [15]	1992	Introduced the f-COCOMO model which applied Fuzzy Logic to the COCOMO model for software effort estimation.	Since there was no comparison of results between the f-COCOMO and other effort estimation models in their study the estimation capability of their model is unknown.
S. Kumar, B.A. Krishna and P.S. Satsangi [16]	1994	Had applied fuzzy logic in Putnam's manpower buildup index (MBI) estimation model. MBI selection process was based upon 64 different fuzzy associative memory (FAM) rules.	The work showed how fuzzy FAM's can be effectively applied to the domain of software project management and control for the estimation of the MBI.
Gray and MacDonell [17]	1997	Compared Function Point Analysis, Regression techniques, feedforward neural network and fuzzy logic in software effort estimation.	Their results showed that fuzzy logic model achieved good performance, being outperformed in terms of accuracy only by neural network model with considerably more input variables.
Gray and MacDonell [18]	1999	Developed FULSOME (Fuzzy Logic for Software Metrics) which is a set of tools that helps in creating fuzzy model.	The automatically generated fuzzy model performs acceptably when compared to regression-based models.
J. Ryder [19]	1998	Researched on the application of fuzzy logic to COCOMO and Function Points models.	Result showed Fuzzy Logic is good at making effort estimations.
P. Musflek, W. Pedrycz, G. Succi and M. Reformat [20]	2000	Worked on fuzzifying basic COCOMO model without considering the adjustment factor. In their simple f-COCOMO model, the size input into the COCOMO model is represented by a fuzzy set, while a and b coefficients are crisp values. Besides the size, augmented f- COCOMO also fuzzified both the coefficients related to the development mode.Triangular membership functions are used in this study.	They concluded that (a) fuzzy sets help articulate the estimates and their essence (by exploiting fuzzy numbers described by asymmetric membership functions) and (b) they generate a feedback as to the given uncertainty (granularity) of the results.
A.Idri, A. Abran, L. Kjiri [21]	2000	Proposed fuzzy intermediate COCOMO'81. The FLM is based upon trapezoidal membership functions. The dataset is randomly generated and compared with actual data of COCOMO' 81. The effort multiplier for each cost driver is obtained from fuzzy	Validation results showed that the fuzzy intermediate COCOMO'81 can tolerate imprecision in its input (cost drivers) and generate more gradual outputs. Thus fuzzy intermediate COCOMO'81 is less sensitive to the changes in the inputs as compared

		set, enabling its gradual transition from one interval to a contiguous interval such as from high to very high).	to intermediate COCOMO'81.
A. Idri, and A. Abran[22]	2002	Proposed a n approach based on fuzzy logic named Fuzzy Analogy. Its dataset is that of COCOMO 81.	Taking into account their results, they suggested the following ranking of the four techniques in terms of accuracy and adequacy to deal with linguistic values: 1. Fuzzy Logic, 2. Fuzzy intermediate COCOMO'81, 3.Classical intermediate COCOMO'81, and 4. Classical Analogy.
Huang, X., Capretz. L.F., Ren, J., Ho. [23]	2003	Proposed a model combining fuzzy logic and neural networks. The dataset was obtained from the original COCOMO (1981).	The results of the fuzzy logic model were better than those of the COCOMO equations. The FLM was based upon triangular membership functions. The main benefit of this model is its good interpretability by using the fuzzy rules.
M.O. Saliu, M. Ahmed and J. AlGhamdi. [24]	2004	They fuzzyfied the two different portions of the intermediate COCOMO model i.e. nominal effort estimation and the adjustment factor. They proposed a fuzzy logic framework for effort prediction by integrating the fuzzified nominal effort and the fuzzified effort multipliers of theintermediate COCOMO model.	This approach is able to deal with uncertainty, provides transparency on prediction rationale through rules, incorporate experts knowledge in the definition of membership functions and rules, as well as adaptable to new data by changing the parameters of membership functions.
Ahmed, M.A., Saliu, M.O. and AlGhamdi, J. [25]	2004	Presented a FLM based upon triangular membership functions. The dataset for validating the FLM was (a) generated randomly and (b) that of COCOMO 81 was used.	Results showed that the FLM was slightly better than COCOMO equations. In addition, they reported promising experimental summary results in spite of the little background knowledge of the rule base and training data.
Crespo, F.J., Sicicila, M.A., Cuadrado, J.J. [26]	2004	Explored fuzzy regression techniques based upon fuzzification of input values. Project database of COCOMO-81 are used.	Fuzzy regression is able to obtain estimation models with similar predictive properties than existing basic estimation models.
M.R. Braz, S.R. Vergilio. [27]	2004	Applied Fuzzy Logic for effort estimation of object-oriented software. FUSP (Fuzzy use case size points) metric allows gradual classifications of use case size points in the effort estimation by using fuzzy numbers.	Results showed that FUSP fares better than USP.
Xu and	2004	Presented a fuzzy identification cost estimation modelling technique to deal with linguistic data, and	It was observed that the fuzzy identification model provided significantly better cost estimations than the three

Khoshgoftaar [28]		automatically generate fuzzy membership functions and rules. A case of study based on the COCOMO'81 database compared the proposed model with all three COCOMO'81 models (basic, intermediate and detailed).	COCOMO'81 models.
L.M.Cuauhtemoc, Y.M. Cornelio and G.T.Agustin. [29]	2006	Carried out a study to compare personal Fuzzy Logic Systems (FLS) with linear regression using evaluation criteria which is based upon ANOVA of MRE and MER, as well as MMRE, MMER and pred(25)	Results show that a FLS can be used as an alternative for estimating the development effort at personal level.
Moon Ting Su, Teck Chaw Ling, Keat Keong Phang, Chee Sun Liew and Peck Yen Man [30]	2007	Proposed an enhanced fuzzy logic model for the estimation of software development effort. The model Fuzzy Logic Model for Software Development Effort and Cost Estimation (FLECE) possesses similar capabilities as the previous fuzzy logic model. In addition to that, the enhancements done in FLECE improved the empirical accuracy of the previous model in terms of MMRE (Mean Magnitude of Relative Error) and threshold- oriented prediction measure or prediction quality (pred).	The analysis of the results shows that FLECE is able to obtain more accurate results in the estimation of software development effort when compared to the previous fuzzy logic model. Hence, the enhancements to FLECE are truly useful and had given better performance to the model.
Venus Marza, Amin Seyyedi, and Luiz Fernando Capretz[31]	2008	Hybrid neuro-fuzzy technique is used for development time and is validated with gathered data.	The results showed that neuro-fuzzy system is much better than two other mentioned methods (fuzzy logic and neural network separately).Hence, In order to achieve more accurate estimation, several techniques maybe combined.
Parvinder S. Sandhu, Porush Bassi, and Amanpreet Singh Brar[32]	2008	Neuro-Fuzzy technique is used for software estimation of NASA software project data and performance of the developed models are compared with the Halstead, Walston-Felix, Bailey-Basili and Doty Models	The performance of the Neuro-fuzzy based effort estimation Model and the other existing Halstead Model, Walston-Felix Model, Bailey-Basili Model and Doty Model models is compared for effort dataset .The results show that the Neuro-fuzzy system has the lowest MMRE and RMSSE values.

Iman Attarzadeh and Siew	2009	Proposed an enhanced Fuzzy Logic approach for the estimation of software development effort.	Results showed that the value of MMRE applying their Fuzzy Logic model was substantially lower than MMRE values

Hock Ow [33]			as calculated by applying other Fuzzy Logic models.
Ch. Satyananda Ready, KVSVN Raju[34]	2009	The proposed work is based on COCOMO dataset and the experimental part of the study illustrates the approach using Gaussian membership function	Result showed the proposed model gives more precise result than that of using the TMF. Thus by using GMF, the accuracy of effort estimation can be improved and the estimated effort can be very close to the actual effort.
Wei Lin Du, Danny Ho, Luiz Fernando Capretz[35]	2010	Proposed an approach combining the neuro-fuzzy technique and the SEER-SEM effort estimation algorithm and evaluate the prediction performance of the proposed neuro-fuzzy model with SEER-SEM in software estimation practices.	Results shows that that combining the neuro-fuzzy model with the SEER-SEM effort estimation model produces unique characteristics and performance improvements. Results also proves that the proposed neuro-fuzzy structure can be used with other algorithmic models besides the COCOMO model.
Abou Bakar Nauman, Romana Aziz[36]	2011	This paper proposes a simple Bayesian Network (BN), based on classification approach. The classes of ranges of size value are distributed with help of fuzzification to distribute the probability of crisp value.	The proposed model shows two specific achievements. 1). Model shows that a smaller Bayesian network can be developed to achieve intelligent effort estimates. 2). The classifications of sizes can be managed with the help of fuzzy logic.
Prasad Reddy P.V.G.D, Sudha K. R, Rama Sree [37]	2011	Software development effort predicted using Fuzzy Triangular Membership Function and GBell Membership Function is implemented and compared with COCOMO using NASA93 dataset.	Results shows that software effort estimation using Fuzzy method with TMF (triangular membership function) is better than Fuzzy method using GBellMF or Intermediate COCOMO. It is not possible to evolve a method, which can give 100 % VAF. By suitably adjusting the values of the parameters in FIS we can optimize the estimated effort.
A.BalaKrishna, T.K.Rama Krishna[38]	2012	The propsed work is to employ Particle Swarm Optimization for tuning the effort parameters, fuzzy logic for reducing uncertainty in input and test its suitability for software effort estimation. This methodology is then tested using NASA dataset provided by Boehm. The results are then compared with the models such as Baily-Basili, Alaa F. Sheta, and Harish models.	Results shows that the proposed model reduce the uncertainty in the input sizes by using fuzzy logic and by lining the parameters of the cost model using PSO with inertia weight in order to generate an optimal result. The model was proved to be efficient on the basis of VARE, MARE and VAF after comparing with the models such as Baily-Basili, Alaa F. Sheta, and Harish models.

3. Conclusion

Although many researchers contributed on cost/effort estimation, still many issues on cost/effort estimation remain unresolved. In this paper we presented a review on the Fuzzy Logic applications in Software development effort estimation models development. We also discussed the various advantages of Fuzzy Logic for developing prediction models. In order to achieve more accurate estimation, voting the estimated values of several techniques and combine their results maybe be useful. Further results can explore using four fuzzy logic membership functions Fuzzy Triangular Membership Function, GBell Membership Function, Gauss Membership Function and Trapezoidal Membership Function and their results will be compared with other estimation models and actual data set of the project. The fuzzy logic models for effort estimation can be deployed on COCOMO II environment for creating an appropriate expert system for providing required information for developing fuzzy sets and an appropriate rule base.

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