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Accuracy of Estimating Project Costs and Benefits: An Overview of Research in Information Systems

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ABSTRACT

Estimating information systems project costs and benefits is a challenging endeavor and is notoriously prone to uncertainties and errors. The purpose of this study is to review research publications on quantitative estimating accuracy of costs and benefits (financial returns). The importance of the problem is due to the wide use of cost and benefits evaluations in making critical business decisions. The study reveals existing quantitative levels of estimating costs and benefits accuracy in the context of the information systems implementations.

Keywords: *Evaluation, costs, benefits, accuracy, estimation error, uncertainty, information system, effort estimation, cost estimation, benefit estimation*

1. INTRODUCTION

Any predicting or forecasting activity is notoriously prone to uncertainties and errors. Estimating future information system (IS) project costs and returns (benefits) also is a challenging endeavor [1-4]. Due to a variety of reasons actual numbers usually differ from the ones estimated in advance. The errors in estimating costs and returns will propagate through the project management and financial systems of the organization implementing a project and may lead to significant inaccuracies of the overall plans, and ultimately destroy the project.

Assessing the accuracy of the costs and returns estimations should be considered an essential part of the IS implementation planning. Neglecting to estimate costs and returns accuracy may lead to wrong decisions on acquisition of information systems.

The purpose of this study is to review research publications on estimating the accuracy of the costs and benefits. The study reveals existing quantitative levels of estimating accuracy in the context of the information systems implementations.

The research is intended to answer the following questions:

- What are the accuracies of estimating project costs of the information systems implementations?
- What are the accuracies of estimating project benefits of the information systems implementations?

Literature review method was used to gather and analyze information related to the accuracy of estimating project costs and benefits.

The scope of the research is to determine the existing levels of accuracy estimation of costs and benefits. The details and processes of the estimation methods are out of the research scope: the focus is on the

resulting attribute of the estimation (accuracy), not on the process of getting to this result.

The overall cost or value of benefits for most information systems projects are a result of summation/combination of several types of costs and benefits. For example, there could be a variety of the benefits types: e.g. increased revenues due to increased sales, or sales margins; revenue enhancement, e.g. additional revenues were gained due to better targeted marketing and advertising; revenue protection, i.e. imminent fine was avoided (due to demonstrated compliance with regulatory requirements); cost savings due to downsizing, i.e. salaries and wages of the full time employees saved due to the system implementation, etc.

Similar variety of types exists for costs: cost of software development or customization/configuration; cost of IT infrastructure, e.g. ; software/licenses - initial and annual maintenance; hardware - if IS run in-house (e.g. purchasing and installation of new servers); hosting - if information system provided as Software as a Service by a third party; cost of labor, e.g. direct operating expenses (DOE); salaries and wages plus benefits for full time equivalent positions; consultant services of installation, configuration, software customization, integration that requires skills not available within the I&IT Department; cost of training, e.g. IT personnel training by a third party or program area end-user training by a third party. We assume that the estimates of costs and value of the benefits (financial returns) are given by single numbers (after the process of accounting of all individual components).

The results of this study are intended for researchers in information systems, technology solutions and business management, and also for information specialists, project managers, program managers, technology directors, and information systems evaluators.

The importance of the problem is due to a wide use of the cost and benefits evaluations in making investment decisions within the process of information systems implementation. The main contribution of the

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study is that it demonstrates the existing level of uncertainties associated with costs and benefits estimation.

The paper is structured as follows. Section 1 provides an introduction, outlines research objectives, defines methodology, and identifies limitations and assumptions of the study. Section 2 reviews research efforts on the accuracy of cost estimations. Section 3 overviews publications on the accuracy of benefit estimations. The paper concludes with a brief discussion and final remarks.

2. COST ACCURACY ESTIMATION

A cluster of publications was retrieved that deal with the accuracy of forecasting costs in various industries and project settings, e.g. [1-4].

A subsection of this cluster deals with the software development effort estimation and its accuracy.

A wide variety of estimation techniques are being used, which could be divided into several categories: estimation by analogy, parametric models, expert estimation, artificial intelligence methods [5-9]. Mostly often used techniques, to name a few, are: COCOMO II (Constructive Cost Model II) [10, 11], Function Point Analysis [12, 13], Use Case Points Method [14, 15], a variety of artificial intelligence (machine learning) methods that are based on neural networks, fuzzy logic, regression trees, rule induction, Bayesian belief networks, evolutionary computation, grey relational models, etc. [16-20].

Several authors compared the cost estimate at different stages of a product lifecycle (especially, at early stages) and the actual costs when the project was completed. The deviation/error of the estimates was documented.

A variety of measures to estimate accuracy are being used [6, 7, 16, 21-24]: Balanced Relative Error (BRE), Balanced Relative Error Bias (BREbias), Magnitude of Error Relative to the estimate (MER), Magnitude of Relative Error (MRE), Magnitude Relative Error Bias (MREbias), Mean Absolute Error (MAE), Mean Absolute Relative Error (MARE), Mean Balanced Relative Error (MBRE), Mean Inverted Balanced Relative Error (MIBRE), Mean Magnitude of Relative Error (MMRE), Mean Variation from Estimate (MVFE), Median Magnitude of Relative Error (MdmRE), Percentage of predictions falling within x% of the actual values (PRED(x%)), Relative Root Mean Squared Error (RRMSE), Root Mean Squared Error (RMSE), Variance Absolute Relative Error (VARE), Weighted Mean of Quartiles of relative errors (WMQ). These measures can be used separately or in combinations.

Although being criticized [23, 24], the Mean Magnitude of Relative Error (MMRE) remains the most commonly used measure. In order to present results of

different papers in a more comparable form, this measure is used in this review (where possible).

Alves, Valente & Nunes assess the accuracy of the software effort estimation performed with two methods: use-case point method (UCP) and UCP method enhanced with human-computer interaction techniques (iUCP) [14]. Seven real world projects were estimated. The authors conclude that Mean Magnitude of Relative Error for iUCP was 34.3% and 69.6% for UCP.

Nassif, Ho & Capretz propose to improve UCP method by employing a novel log-linear regression model and multilayer perceptron (MLP): feed-back neural network [7]. The purpose of this work is to tackle limitations of the original UCP method, namely the assumption of the linear relationship between the software size and effort, and exclusion of the team productivity from the estimating effort. Seventy projects were evaluated. The accuracy of the effort estimation for the log-linear regression model, MLP and standard UCP were respectively: 39.2%, 40% and 46.7% (MMRE). For a subset of the data which included only small projects (under 3,000 person-hours), MLP outperformed other models.

Zapata & Chaudron explore the accuracy of the budget, effort and schedule estimates based on a set of 171 projects undertaken by a large Dutch multinational company during a three-year period [22, 23]. The MMRE for the budget and effort predictions are 26% and 103% respectively. The study shows that there were no relation between accuracy of budget, schedule and effort. Also, the study found that there was no improvement in the organization's accuracy estimation over time.

Attarzadeh & Ow proposed a fuzzy model to enhance COCOMO II. They conclude that their model is more accurate than COCOMO: MMRE 37% over 41% respectively [25].

Song & Shepperd proposed a model based on grey relational analysis to address outlier detection, feature subset selection and effort prediction, and compared this model with stepwise regression model [20].

The resulted accuracy on the Desharnais data set – part of the PROMISE Software Engineering Repository [26] was 41.4% for grey model versus 46.5% for stepwise regression model (MMRE).

In many papers, including some of those mentioned above, authors analyze and compare two to three estimating methods. Usually, a new or improved method proposed by the authors is compared to one of the most commonly used (e.g. UCP, COCOMO). Toka and Turetken offer a broader scope [27]. They investigate accuracy of the COCOMO II, SEER-SEM, SLIM by QSM, and True Planning by PRICE Systems in the same context. All methods are compared using a variety of performance measures for both project effort and duration

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based on a set of 56 projects. The authors conclude that the COCOMOII model is inferior to the other three in estimating effort (MMRE 74% vs 34-41%), and that the results for all four methods cannot be statistically differentiated with respect to duration (MMRE 81-99%).

Azzeh, Neagu & Cowling compare several models: estimation by analogy enhanced with fuzzy grey relational analysis, case-based reasoning, multiple linear regression and artificial neural networks. The resulted accuracy on the Desharnais data set was 30.6%, 38.2%, 39.9%, 61.2%, respectively (MMRE) [28].

Keung, Kocaguneli & Menzies offer even broader scope which includes most available historical data sets, performance measures and estimating methods [21]. However, the results are presented in the form of ranking estimating methods without providing actual accuracy values.

The literature review revealed several important notions shared by many researchers:

- Cost prediction for software development projects is prone to errors.
- Estimates are mostly overoptimistic and underestimating is a problem for the software industry [25, 29]. 60-80% of the projects experience effort or schedule average overruns of 30-40% [30].
- A known cone of uncertainty illustrates that the variation of costs for the initial project phase could have as much as a +/-400% error [25]. The authors of the [31] referring to an earlier study indicate that cost estimates at the conceptual stage are in the range of -30% to +50%, which reduces to between -5% and +15% when the detailed design phase is entered.
- Factors, contributing to the estimation errors, include: estimation process complexity, volatile and unclear requirements, redefinition of requirements under pressure from senior management and clients, lack of experienced resources for estimation, misuse of estimates, technical complexity, requirements redefinition, business domain instability, selection of a proper estimation technique, managerial issues [5, 23, 32, 36].

Most authors admit limitations of the accuracy estimating studies [18, 27]: the first is incomplete project data affecting the accuracy of estimations and the second is limited number of projects with data on actual costs making results less reliable. These limitations pose risks on the validity of the estimation results.

Table I illustrates estimating errors collected from 15 studies.

For better visualization, collected cost/effort error estimates are presented in Fig. 1. Two outliers: 9%

and 1,218% were not included. The graph demonstrates that 75% of the sample error estimates fall within the error range of 20% to 60%.

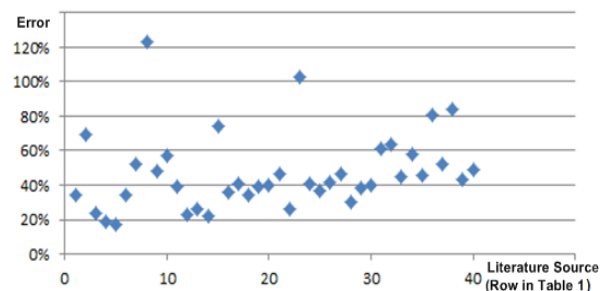


Fig 1: Sample graph of cost/effort error estimates

A histogram in Fig.2 shows that within the error range of 20% to 60% most likely value of error is from 30% to 50%.

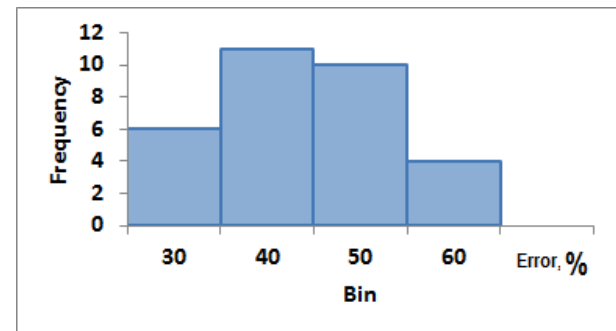


Fig 2: Histogram of cost/effort error estimates within the 20 to 60% range

3. FINANCIAL RETURNS / BENEFITS ACCURACY ESTIMATING

Estimation of the financial returns received much less attention in the academic literature than estimation of the costs. The main reasons for that are the difficulties identifying, quantifying and monetizing benefits [38-44].

There are certain explanations for that:

- Actual costs are recorded through the project life and finalized at the end of the project. Benefits are only starting to emerge and accrue when the implementation is completed [40]. Usually, there are no processes and information systems to record value of benefits. After the project has been closed, there is just nobody to collect and explore the data.
- A commonly documented type of benefit is worker productivity gain and related time and, consequently, financial savings. Obviously, these savings can be realized only if certain percent of the workforce is terminated after the system implementation [40, 45]. However, there is no body of evidence to substantiate this being a regular practice. Hence, there is lack of data to

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support initial project benefit estimates or to measure variances.

- In subsection 2.2, we stated that there is lack of costs historical data. Regarding benefits we should admit that there is almost no benefits data. Companies consider benefits data even more confidential than cost information.
- The direct impact of the information system implementation project is difficult to establish [43].
- Measuring benefits, which may be tangible, quasi-tangible and/or intangible, is another challenge [40].
- Lack of research and commonly accepted benefits estimating methods [44]. “Effective methods for modelling software benefits tend to be highly domain-specific” [11].

Another challenge is the evolution of the information systems and their respective benefits over time. This process is illustrated on Fig. 3 (based on [43, 46, 47]). The chart demonstrates that modern information systems tend to deliver benefits (in full accordance with the purposes they were created for) that are largely intangible and hardly can be estimated in financial terms, e.g. enhanced collaboration, more pertinent search results, etc. [40-42, 44]. It should be noted that the horizontal axis on Fig. 3 is not a timeline and the figure should not be understood in the way that modern IS do not are based totally on knowledge and not on data. The figure illustrates the innovation trend.

Identification of benefits should be closely aligned with the systems’ goals/objectives. The desire to find hard-dollar benefits (inherent to older generations of the information systems) may divert researchers’ attention from assessing the actual benefits of the systems.

For example, measuring benefits of the enterprise content management (ECM) system only by the volume of computer memory (and hence actual dollars saved as a result of reduced document duplication) may seem to be simple and attractive, but questionable, because it doesn’t reflect the benefits the system was designed to provide. Another example is the way the web conferencing systems (WCS) benefits are presented.

Often, these benefits are limited to the savings on travel for meeting participants that these systems offer plus even more popular and appealing “green effects” (reducing carbon emissions due to eliminating travel). At least reduced travel can be easily estimated in the employees’ time savings and expressed in dollars. However, the actual benefit – value added – visual collaboration (on content and personal) will not be accounted for.

Bojanc&Jerman-Blažicinvestigate return on IT security investment [39]. In this case the benefits are viewed as cost savings gained because of decreased probability of a security incident due to the

implementation of security measures. The authors state that such benefits are very hard to predict accurately.

Driessen et al. evaluate ROI for a hospital electronic medical record (EMR) system [48]. Financial benefits are estimated based on the expected cost savings due to reduction of length of stay, transcription time and laboratory time. The reduction of these three parameters is considered to be a result of the efficiency gained with EMR implementation. Calculation of the benefits is based on a number of assumptions. For example, reduction of length of stay is expected to be 10.5% based on research published by other authors. The number was selected as a conservative estimate from a range of similar published assessments with a high level going up to 30%. In its turn, reduction in length of stay will save inpatients meals and clinical staff time. Clinical staff (nurses and doctors) is assumed to spend 60% in managing inpatients.

Assessments of the time saved then converted into financial benefits. The assumptions, adopted in this case, bring in significant uncertainties. All of them are heavily dependent on multiple specific parameters of the hospital location, bed-size, processes used, configuration of the EMR system, etc. There are neither established methods nor historical databases to verify the accuracy of the calculated benefits.

Uzokaproposes a framework to analyze benefits and costs of the enterprise information systems [41]. The purpose is to enhance the expert judgement, which is perceived to be subjective; by a fuzzy logic model. The framework has a theoretical nature and examples of its actual use with quantitative assessments are not provided.

Wagner, Xie, Rübél-Otterbach& Sell propose a profitability estimation method for software projects dubbed SW-WiBe [44]. This framework is based on the expert assessments of quantifiable and non-quantifiable benefits enhanced with Delphi process.

Lewis & Rao analyze the benefits of advertising and state that determination of statistically sound evidence of the returns to advertising is very difficult, even when researching large campaigns with millions of observations [49].

Some studies attempted to create a high-level frameworks to capture systems benefits: e.g. capture IT capability from a hospital IT portfolio perspective [50] or examine the overall relationship between IT utilization and financial performance in hospitals [38].

The literature review didn’t reveal any studies neither on the methodology of estimating accuracy of predicted benefits nor on actual numbers based on the case studies.

As the literature review reveals, methods used to estimate benefits are similar to those used to estimate costs: analogy [48], expert judgement [43, 44], expert

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judgement enhanced with fuzzy models [41], etc. That led us to the assumption that we can expect the same (or larger) quantitative levels of benefits estimation accuracy as we experience for cost estimation accuracy.

4. DISCUSSION AND CONCLUDING REMARKS

The study performed data collection and analysis on the accuracy of cost and benefit estimates in the context of information systems projects. The importance of the problem is due to a wide use of the cost and benefits evaluations in making investment and other critical business decisions.

The study retrieved and reviewed multiple publications which contain quantitative assessments of project cost accuracy. Despite a criticism of providing biased results, the Mean Magnitude of Relative Error (MMRE) remains the most commonly used measure of estimate error. The review indicates that in 75% of the projects the cost error estimates fall within the range of 20% to 60% with most likely value of error from 30% to 50%.

Research on quantification of benefits (financial returns) falls behind studies of cost estimates in the academic literature. Hence, the literature review didn't reveal any studies neither on the methodology of estimating accuracy of predicted benefits nor on actual numbers based on the case studies. The assumption that could be drawn is that we could expect the same (or larger) quantitative levels of benefits estimation accuracy as we experience for cost estimation accuracy.

The main contribution of the study is that it demonstrates the existing quantitative levels of uncertainties associated with costs and benefits estimation. These levels can be used for project planning, developing risk mitigating measures and simulation modeling of project results. Estimating accuracy of the costs and benefits calculations should become a part of the project planning best practices in order to avoid erroneous investment decisions.

Future research may be focused on developing a framework of identification, quantification and monetization benefits and presenting benefits accuracy in a standardized way.

Table 1: Sample Estimating Errors by Method/Technique

S.No	Estimation Method/Model	Estimated Project Parameter	Error Measure	Error/Accuracy	Reference
1	UCP	Cost	MMRE	34.3%	[14]
2	iUCP	Cost	MMRE	69.6%	[14]
3	UCP	Cost	MMRE for 95% of the projects	9%	[33]
4	N/A	Duration	MMRE	22%	[5]
5	N/A	Effort	MMRE	24%	[5]
6	Intermediate COCOMO	Effort	MMRE	18.6%	[16]
7	Radial Basis Neural Network	Effort	MMRE	17.3%	[16]
8	Generalized Regression Neural Network	Effort	MMRE	34.6%	[16]
9	COCOMO	Effort	MMRE	52%	[17]
10	Levenberg-Marquardt Based Neural Network	Effort	MMRE	123%	[17]
11	Back Propagation Based Neural Network	Effort	MMRE	1,218%	[17]
12	Bayesian Regularization Based Neural Network	Effort	MMRE	48%	[17]
13	SEER-SEM	Effort	MMRE	57%	[18]
14	SEER-SEM Enhanced with Neuro-Fuzzy Model	Effort	MMRE	39%	[18]
15	COCOMO Enhanced with Computing Intelligence Techniques	Effort	MMRE	23%	[34]
16	COCOMO	Effort	MMRE	26%	[34]
17	Fuzzy Neural Network	Effort	MMRE	22%	[35]
18	COCOMOII	Effort	MMRE	74%	[27]
19	COCOMOII	Duration	MMRE	91%	[27]
20	SEER-SEM	Effort	MMRE	36%	[27]
21	SEER-SEM	Duration	MMRE	81%	[27]
22	SLIM by QSM	Effort	MMRE	41%	[27]

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S.No	Estimation Method/Model	Estimated Project Parameter	Error Measure	Error/Accuracy	Reference
23	SLIM by QSM	Duration	MMRE	84%	[27]
24	True Planning by Price Systems	Effort	MMRE	34%	[27]
25	True Planning by Price Systems	Duration	MMRE	99%	[27]
26	UCP with log-linear regression model	Effort	MMERE	39.2%	[7]
27	UCP with Multilayer Perceptron (MLP)	Effort	MMERE	40%	[7]
28	UCP	Effort	MMERE	46.7%	[7]
29	N/A	Cost	MMRE	26%	[22]
30	N/A	Effort	MMRE	103%	[22]
31	COCOMO II	Effort	MMRE	41%	[25]
32	COCOMO II enhanced with Fuzzy Model	Effort	MMRE	37%	[25]
33	Grey Relational Model	Effort	MMRE	41.4%	[20]
34	Stepwise Regression Model	Effort	MMRE	46.5%	[20]
35	Estimation by Analogy enhanced with fuzzy grey relational analysis	Effort	MMRE	30.6%	[28]
36	Case-Based Reasoning	Effort	MMRE	38.2%	[28]
37	Multiple Linear Regression	Effort	MMRE	39.9%	[28]
38	Artificial Neural Networks	Effort	MMRE	61.2%	[28]
39	Intermediate COCOMO	Effort	MMRE	64%	[37]
40	COCOMO II	Effort	MMRE	45%	[37]
41	MOPSO Model	Effort	MMRE	58%	[37]
42	Support Vector Regression (SVR) Model	Effort	MMRE	46%	[37]
43	Software Engineering Laboratory (SEL) Model	Effort	MMRE	81%	[37]
44	Walton-Felix Model	Effort	MMRE	52%	[37]
45	Bailey-Basil Model	Effort	MMRE	84%	[37]
46	Halsted Model	Effort	MMRE	43%	[37]
47	Doty Model	Effort	MMRE	49%	[37]

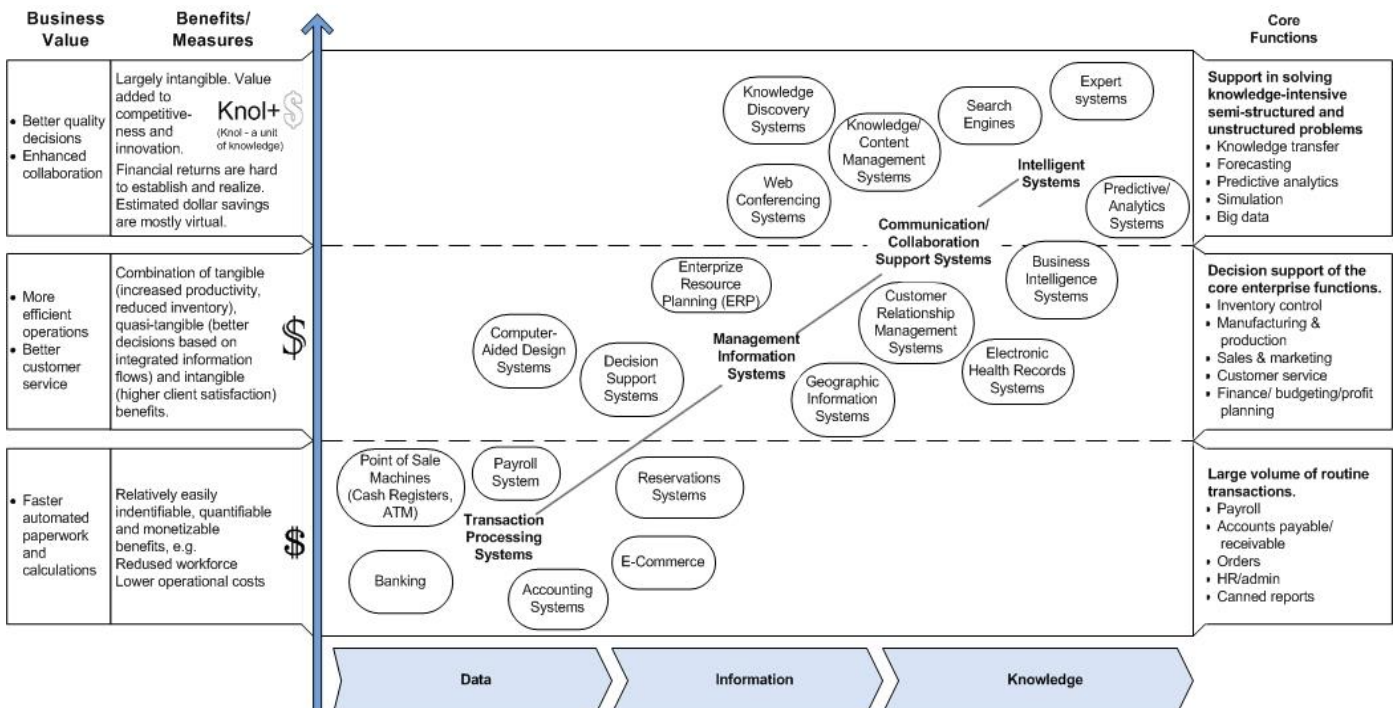


Fig 3: Evolution of the Information Systems and their Benefits

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REFERENCES

- [1] Stamelos, I., Angelis L. (2001). Managing uncertainty in project portfolio cost estimation. *Information and Software Technology*, 43(13), 759-768. Doi: 10.1016/S0950-5849(01)00183-5
- [2] Daneva, M., and Wieringa, R. (2008). Cost estimation for cross-organizational ERP projects: research perspectives. *Software Quality Journal*, 16(3), 459-481. Doi: 10.1007/s11219-008-9045-8
- [3] Eckartz, S. M. (2009). Costs, Benefits and Value Distribution - Ingredients for Successful Cross-Organizational ES Business Cases. In: 32nd Information Systems Research Seminar in Scandinavia, IRIS 32, Inclusive Design, 9-12 August 2009, Molde, Norway.
- [4] Jorgensen, M., Shepperd, M. (2007). A Systematic Review of Software Development Cost Estimation Studies. *IEEE Transactions on Software Engineering*, 33(1), 33-53. doi:10.1109/TSE.2007.256943
- [5] Morgenshtern, O., Raz, T., & Dvir, D. (2007). Factors affecting duration and effort estimation errors in software development projects. *Information and Software Technology*, 49(8), 827-837.
- [6] Basha, S., & Ponnuram, D. (2010). Analysis of empirical software effort estimation models. *International Journal of Computer Science and Information Security*, 7(3), 68-77. arXiv preprint arXiv:1004.1239
- [7] Nassif, A. B., Ho, D., & Capretz, L. F. (2013). Towards an early software estimation using log-linear regression and a multilayer perceptron model. *Journal of Systems and Software*. 86(1), 144-160. <http://dx.doi.org/10.1016/j.jss.2012.07.050>
- [8] Khatibi, V., & Jawawi, D. N. (2011). Software cost estimation methods: A review. *Journal of emerging trends in computing and information sciences*, 2(1), 21-29.
- [9] Buglione, L., & Ebert, C. (2011). Estimation Tools and Techniques, *IEEE Software*, 28(3), 15-18.
- [10] COCOMOII Constructive Cost Model II http://sunset.usc.edu/csse/research/COCOMOII/comeo_main.html
- [11] Boehm, B., Abts, C., Brown, A.W., Chulani, Clark, B.K., Horowitz, E., Madachy, R., Reifer, D.J., and Steece, B. (2000). *Software Cost Estimation with COCOMO II with CD-ROM*. Englewood Cliffs, NJ: Prentice-Hall. ISBN 0-13-026692-2
- [12] Albrecht, A.J. (1979) Measuring Application Development Productivity, Joint SHARE/GUIDE/IBM Application Development Symposium, 83-92.
- [13] Lavazza, L., & Morasca, S. (2013). Measuring the Functional Size of Real-Time and Embedded Software: a Comparison of Function Point Analysis and COSMIC. In ICSEA 2013, the Eighth International Conference on Software Engineering Advances, 465-470.
- [14] Alves, R., Valente, P., & Nunes, N. J. (2013). Improving Software Effort Estimation with Human-Centric Models: a comparison of UCP and iUCP accuracy. In Proceedings of the 5th ACM SIGCHI symposium on Engineering interactive computing systems, EICS '13, 33-42, New York, NY, USA. ACM. DOI=10.1145/2480296.2480300 <http://doi.acm.org/10.1145/2480296.2480300>
- [15] Chemuturi, M. (2009). Software Estimation Best Practices, Tools and Techniques for Software Project Estimators, J. Ross Publishing, 84-87.
- [16] Reddy, P. V. G. D., Sudha, K. R., Sree, P. R., & Ramesh, S. N. S. V. S. C. (2010). Software effort estimation using radial basis and generalized regression neural networks. *Journal of Computing*, 2(5), ISSN 2151-9617 arXiv preprint arXiv:1005.4021. <http://arxiv.org/ftp/arxiv/papers/1005/1005.4021.pdf>
- [17] Kaur, H. Salaria, DS. (2013). Bayesian Regularization Based Neural Network Tool for Software Effort Estimation. *Global Journal of Computer Science and Technology*, 13(2). <http://computerresearch.org/stpr/index.php/gjcst/article/viewPDFInterstitial/1381/1247>
- [18] Du, W. L., Capretz, L. F., Nassif, A. B., & Ho, D. (2013). A Hybrid Intelligent Model for Software Cost Estimation. *Journal of Computer Science*, 9(11), 1506. <http://thescpub.com/abstract/10.3844/jcssp.2013.1506.1513>
- [19] Muzaffar, Z., & Ahmed, M. A. (2010). Software development effort prediction: A study on the factors impacting the accuracy of fuzzy logic systems. *Information and Software Technology*, 52(1), 92-109.
- [20] Song, Q., & Shepperd, M. (2011). Predicting software project effort: A grey relational analysis based method. *Expert Systems with Applications*. 38(6), 7302-7316. <http://zema.gr.xjtu.edu.cn/LiferayFCKeditor/UserFiles/File/QSong/Paper/ESWA5582.pdf>

<http://www.cisjournal.org>

- [21] Keung, J., Kocaguneli, E., Menzies, T. (2011). A ranking stability indicator for selecting the best effort estimator in software cost estimation. *Automated Software Engineering* (submitted) Available on-line at <http://menzies.us/pdf/11drafranking.pdf>
- [22] Zapata, A. H., & Chaudron, M. R. (2012). An analysis of accuracy and learning in software project estimating. In *Software Engineering and Advanced Applications (SEAA), 2012 38th EUROMICRO Conference on*, 414-421 IEEE.
- [23] Zapata, A. H., & Chaudron, M. R. V. (2013). An Empirical Study into the Accuracy of IT Estimations and its Influencing Factors. *International Journal of Software Engineering and Knowledge Engineering*. 23(4), 409-432.
- [24] Jørgensen, M. (2007). A critique of how we measure and interpret the accuracy of software development effort estimation. In *First International Workshop on Software Productivity Analysis and Cost Estimation*. Information Processing Society of Japan, Nagoya. <http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.110.4666&rep=rep1&type=pdf#page=25>
- [25] Attarzadeh, I., & Ow, S. H. (2010). Improving the accuracy of software cost estimation model based on a new fuzzy logic model. *World Appl. Sci. J*, 82(2), 177-184. <http://www.idosi.org/wasj/wasj8210/7.pdf>
- [26] PROMISE Software Engineering Repository. (n.d.) <http://promise.site.uottawa.ca/SERepository/dataset-page.html>
- [27] Toka, D., Turetken, O. (2013). Accuracy of Contemporary Parametric Software Estimation Models: A Comparative Analysis. 39th Euromicro Conference on Software Engineering and Advanced Applications SEAA 2013 IEEE, 313-316. <http://dx.doi.org/10.1109/SEAA.2013.49>
- [28] Azzeh, M., Neagu, D., & Cowling, P. I. (2010). Fuzzy grey relational analysis for software effort estimation. *Empirical Software Engineering*, 15(1), 60-90. https://pure.york.ac.uk/portal/files/13014230/fuzzy_logic_fugreansoefes.pdf
- [29] McConnell, S. (2009). *Software Estimation: Demystifying the Black Art: Demystifying the Black Art*. O'Reilly Media, Inc.
- [30] Molokken, K., & Jorgensen, M. (2003). A review of software surveys on software effort estimation. In *Empirical Software Engineering, ISESE 2003*. Proceedings. International Symposium on, 223-230. IEEE.
- [31] Goh, Y. M., Newnes, L. B., Mileham, A. R., McMahon, C. A., & Saravi, M. E. (2010). Uncertainty in Through-Life Costing--Review and Perspectives. *Engineering Management, IEEE Transactions on*, 57(4), 689-701.
- [32] Yang, D., Wang, Q., Li, M., Yang, Y., Ye, K., & Du, J. (2008). A survey on software cost estimation in the chinese software industry. In *Proceedings of the Second ACM-IEEE international symposium on Empirical software engineering and measurement*. 253-262. ACM.
- [33] Carroll, E. R. (2005). Estimating software based on use case points. In *Companion to the 20th annual ACM SIGPLAN conference on Object-oriented programming, systems, languages, and applications*. 257-265. ACM.
- [34] Lin, J. C., Lin, Y. T., Tzeng, H. Y., & Wang, Y. C. (2013). Using Computing Intelligence Techniques to Estimate Software Effort. *International Journal of Software Engineering & Applications IJSEA*, 4(1), 43-53. http://www.aircse.org/journal/ijsea/papers/4113ijs_ea04.pdf
- [35] Huang, S. J., & Chiu, N. H. (2009). Applying fuzzy neural network to estimate software development effort. *Applied Intelligence*, 30(2), 73-83.
- [36] Venkataraman, R. R., & Pinto, J. K. (2011). *Cost and value management in projects*. John Wiley & Sons.
- [37] Kumari, S., & Pushkar, S. (2013). Performance Analysis of the Software Cost Estimation Methods: A Review. *International Journal of Advanced Research in Computer Science and Software Engineering*, 3(7), 229-238. http://www.ijarcsse.com/docs/papers/Volume_3/7_July2013/V3I7-0247.pdf
- [38] Menachemi, N., Burkhardt, J., Shewchuk, R., Burke, D., & Brooks, R. G. (2006). Hospital information technology and positive financial performance: a different approach to finding an ROI. *Journal of Healthcare Management. American College of Healthcare Executives*, 51(1), 40-58.
- [39] Bojanc, R., & Jerman-Blažič, B. (2012). Quantitative Model for Economic Analyses of Information Security Investment in an Enterprise Information System. *Organizacija* 45(6), 276-288. DOI: 10.2478/v10051-012-0027-z

<http://www.cisjournal.org>

- [40] Irani, Z., & Love, P. (Eds.) (2013). *Evaluating Information Systems*. Routledge.
- [41] Uzoka, F. M. E. (2009). Fuzzy-Expert system for cost Benefit Analysis of Enterprise information systems, A Frame work. *International Journal on Computer Science and Engineering*, 1(3), 254-262.
- [42] Laudon, K.C., Laudon, J.P., (2005). *Essentials of Management Information Systems: Managing the Digital Firm*, Sixth ed., Prentice Hall, Upper Saddle River, New Jersey,.
- [43] Vogel, L. H. (2002). Finding value from IT investments: exploring the elusive ROI in healthcare. *Journal of healthcare information management*. *JHIM*, 17(4), 20-28.
- [44] Wagner, S., Xie, S., Rübél-Otterbach, M., & Sell, B. (2007). Profitability estimation of software projects: A combined framework. In *The First International Workshop on Software Productivity Analysis and Cost Estimation (SPACE'07)*. 37-43.
- [45] Sidorov, J. (2006). It ain't necessarily so: the electronic health record and the unlikely prospect of reducing health care costs. *Health Affairs*, 25(4), 1079-1085. Doi: 10.1377/hlthaff.25.4.1079 <http://content.healthaffairs.org/content/25/4/1079.full.html>
- [46] Smith, R., Burnett, S. (2003). Beyond first-generation KM. *inside Knowledge* 6(7). http://www.ikmagazine.com/xq/asp/sid.0/articleid.DE0ADE1B-4060-49F7-B0F1-CC75898E101C/eTitle.Beyond_firstgeneration_KM/qx/display.htm
- [47] Matthews, J., (2013). Adding value: getting to the heart of the matter. *Performance Measurement and Metrics*, 14(3),162 - 174. DOI: 10.1108/PMM-08-2013-0024
- [48] Driessen, J., Cioffi, M., Alide, N., Landis-Lewis, Z., Gamadzi, G., Gadabu, O. J., & Douglas, G. (2013). Modeling return on investment for an electronic medical record system in Lilongwe, Malawi. *Journal of the American Medical Informatics Association*, 743-748 doi:10.1136/amiajnl-2012-001242
- [49] Lewis, R. A., & Rao, J. M. (2013). On the Near Impossibility of Measuring the Returns to Advertising. ftp://ftp.zew.de/pub/zew-docs/veranstaltungen/ICT2013/Papers/ICT2013_Rao.pdf
- [50] Burke, D. E., & Menachemi, N. (2004). Opening the black box: Measuring hospital information technology capability. *Health Care Management Review*, 29(3), 207-217.

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