

Training and Re-using Human Experience: A Recommender for More Accurate Cost Estimates in Project Planning

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Abstract: In many industries, companies deliver customised solutions to their (business) customers within projects. Estimating the human effort involved in such projects is a difficult task and underestimating efforts can lead to non-billable hours, i.e. financial loss on the side of the solution provider. Previous work in this area has focused on automatic estimation of the cost of software projects and has largely ignored the interaction between automated estimation support and human project leads.

Our main hypothesis is that an adequate design of such interaction will increase the acceptance of automatically derived estimates and that it will allow for a fruitful combination of data-driven insights and human experience. We therefore build a recommender that is applicable beyond software projects and that suggests job positions to be added to projects and estimated effort of such positions. The recommender is based on the analysis of similar cases (case-based reasoning), “explains” derived similarities and allows human intervention to manually adjust the outcomes. Our experiments show that recommendations were considered helpful and that the ability of the system to explain and adjust these recommendations was heavily used and increased the trust in the system. We conjecture that the interaction of project leads with the system will help to further improve the accuracy of recommendations and the support of human learning in the future.

1 INTRODUCTION

In industries such as consulting, design or software development, companies deliver non-standardised, custom solutions to their customers within projects. Before a project starts, the solution provider usually creates an offer in which the required (human) effort is estimated.

On the one hand, this offer needs to be competitive and avoid any unnecessary cost for the customer, on the other hand, significantly underestimating the effort leads to non-billable hours and thus financial loss on the side of the provider. Of course, at the outset of a project, there is a high uncertainty regarding project risks, involved staff etc., which can lead to deviations between estimated and actual effort by a factor of up to four, as an early survey on software development projects by Boehm (1984) has shown.

However, project leaders can learn and improve their estimates based on experiences from past projects: as they lead projects through various phases, they see how certain patterns emerge and can learn e.g. to better judge the complexity of recurring tasks.

In some areas, such patterns and experiences have been collected and published for common reference (Jorgensen, 2005).

Since project leaders usually only see a fraction of a company’s projects and since tasks, estimates and actual costs are often formally captured in information systems, automating the estimation based on such historical project data has attracted researchers’ interest (Chulani et al., 1999), also and especially in the area of machine learning (see e.g. (Štolfa et al., 2013)).

There are indications that humans tend not to fully trust automatically derived estimates, especially when it is impossible to trace them – as would be the case for e.g. a regression based on a neural network (Leung, 2002). Accordingly, analogy-based estimation (ABE) has been shown to be an effective estimation method (Ruhe et al., 2003) since it mimicks human problem solving based on analogies between projects and hence gives the humans a better understanding of the result.

As we will discuss in Section 2, there is a great wealth of work in the area of effort estimation for

software development. In our work, we aim at a more general method that is able to estimate efforts in arbitrary domains. To achieve this, we make a second and more important contribution: we explicitly address the *interaction* between automated components and a human project lead. This interaction will make it possible to benefit and learn from human experience without modeling it formally in advance. As we will show, it will furthermore increase both the acceptance of the estimations and their quality.

The remainder of this paper is structured as follows: Section 2 gives an overview of related work in the area of effort estimation. In Section 3, we describe the methodology of our research, before proposing our semi-automated effort estimation approach in Section 4. Section 5 summarises the results of our evaluation and Section 6 the conclusions drawn from it.

2 RELATED WORK

Effort estimation is an essential prior step in projects to satisfy tight constraints in terms of limited resources. A successful project with a valid effort estimation involves planning and decision-making since time and money is usually limited.

As Boehm (1984) identified, estimating is difficult because resource investments in system analysis and demand planning have to be defined at the beginning of a software project and decisions about the test volume and the priority of product improvements can only be made in later project phases. Moløkken-Østvold and Jørgensen (2003) analysed data sets from companies in the software industry to see why effort estimation projects failed, with the result that 60-80% of the analysed projects were above the budget and lasted longer than the proposed schedule.

2.1 Methods for Effort Estimation

As observed in the study by Moores and Edwards (1992), expert-based estimation by a comparison of similar past projects was identified as the most frequently used method for cost estimation. Besides, Boehm et al. (2000) summarised six categories of estimation approaches in software development cost estimation:

- **Model-based** approaches mostly involve a proprietary algorithmic model, where the effort prediction is often based on "off-the-shelf" formulas.
- **Expert-based** knowledge of previous/known projects that are most commonly used in companies,

which can be supported by experience management approaches such as Case-Based Reasoning (CBR).

- **Learning-oriented** approaches are focusing on learning from explicit knowledge such as Artificial Neural Networks (ANNs) or CBR as well.
- **Dynamic-based** methods try to consider changes such as the effort or cost factors change, during the project lifetime in projects, in their predictions.
- **Regression-based** techniques – as an especially important form of machine learning approaches – are a favourite way of building models, such as Ordinary Least Squares (OLS), which is a well-suited technique when much data is available.
- **Composite** techniques are the sixth category in the list by incorporating several of the mentioned techniques such as a combination of regression-based techniques with model-based and learning-oriented methods.

For this paper, composite techniques integrating expert-based effort estimation and learning-oriented approaches were identified as the most appropriate as they allow involvement of an expert to gain trust and also permit a high level of transparency to make meaningful recommendations.

2.2 Case-based Reasoning

Case-based reasoning (CBR) can be seen as "reasoning by remembering" (Leake, 1996, p. 2) or "reasoning from reminding" (Madhusudan et al., 2004) and as a technically independent methodology (Watson, 1999) for humans and information systems (Martin and Hinkelmann, 2018). "Case-based reasoning is both [...] the ways people use cases to solve problems and the ways we can make machines use them" (Kolodner, 1993, p. 27). Bergmann et al. (2009) regard CBR as a sub-field of artificial intelligence with its roots in cognitive science, machine learning and knowledge-based systems. "CBR uses the knowledge of previously experienced cases to propose a solution to a problem" (Martin and Hinkelmann, 2018, p. 48).

The general CBR methodology can be explained using the four R's of the CBR cycle of Aamodt and Plaza (1994), which are as follows (Martin et al., 2016, p. 3-4):

1. *Retrieve* the most similar case(s) from the case base (knowledge repository).
2. *Reuse* the lesson from the retrieved case(s) as the suggested solution for the new situation.

3. *Revise* the new case after evaluating it in the new situation (problem).
4. *Retain* useful experience for future reuse.

The *Retrieve* step within CBR requires a *similarity model* to compare case characterisations based on the vocabulary containing specific features (Martin and Hinkelmann, 2018). Similar, the reuse of CBR requires an *adaptation model* to provide an adequate adaptation of a previous solution to the current situation (Martin and Hinkelmann, 2018).

2.3 Analogy-based Estimation

In the field of effort estimation, CBR has been widely used for solving problems encountered by project managers in the area of software engineering. Analogy-Based Estimation (ABE) is, therefore, a form of CBR (also known in effort estimation as Estimation By Analogy (EBA)). The idea behind ABE is to compare a project, the current situation, with similar historical projects from the case base.

Thus, the effort of the target project is determined as a function of the known efforts of its similar projects (Li et al., 2007; Shepperd and Schofield, 1997). Four components are included in ABE: (1) a historical data-set, (2) a similarity function, (3) retrieval rules and (4) a solution function.

Based on Ruhe et al. (2003), ABE performed best in 60% of the cases, compared to purely expert-based (without considering CBR) and model-based effort estimation. ABE has many advantages such as a better acceptance of results by users (Leung, 2002; Walkerden and Jeffery, 1999), the ability to deal with poorly understood domains (Walkerden and Jeffery, 1999), the applicability in the very early phase of projects (Leung, 2002) and minimisation of outliers (Walkerden and Jeffery, 1999).

Because of their transparency and ability to explain estimates, CBR/ABE were identified as the most promising basic approach for this research. However, there are two gaps that we wish to close: firstly, these approaches have not been applied systematically to effort estimation in areas other than software development. Secondly, besides explanation of estimates, we explore the possibility of *interaction*, allowing humans to contribute their own experience to improve the estimates of the machine.

3 METHODOLOGY

Design science research (DSR, Vaishnavi and Kuechler (2004)) was used as the main method of this

study. Conducting DSR in two iterations allowed to evaluate early a generic hypothesis and refine the system for the final realisation.

Starting with the awareness phase, the problem was observed and validated from primary data, a focus group and structured observations (Shaughnessy et al., 2012):

- The **data analysis** was performed on a data base of projects, containing both estimates and actual efforts and allowed to study the problem of non-billable hours from primary data.
- Eight experienced project leaders participated in the **focus group**. Participants were tasked to individually estimate two fictitious project cases to bring up and discuss problems in effort estimation and non-billable hours. Further, problems experienced in past projects were brought up and discussed by participants, along with problems coming from the prior data analysis.
- To understand the procedure and problems in the offer creation process (including the effort estimation), four project leaders were observed during offer creation of two historical cases. These **structured observations** helped to understand the process better and to know exactly where to provide support for the estimator.

The outcome was then analysed and a generic hypothesis was formed. Taking account of data analysis outcome and findings from the focus group, the goal of the suggestion phase was to find meaningful data (e.g. features) that could be used for the system (Section 4.3).

Based on those findings, a prototype targeting recognised problems was built and a formative evaluation was performed with qualitative research methods, involving estimators to test the prototype and to get feedback for the second iteration.

Within the second iteration, findings from the formative evaluation in iteration 1 were used to refine the system. During the second iteration, the final system was planned and built. At the end, a summative evaluation was performed, where project leads were involved to perform the entire process of offer creation with the help of the system and to observe their acceptance of recommendations.

4 SUPPORT FEATURES FOR EFFORT ESTIMATION

The main goal of our research is to support effort estimation by combining expert-based with learning-

oriented methods. Learning-oriented are often accurate in predicting effort from sample data, whereas the final decisions are usually made by humans. Decision makers therefore need to fully trust data coming from learning-oriented methods. This means that they need to receive actionable recommendations and understand how they were derived.

ABE as a special form of CBR supports practitioners in the effort estimation process in a familiar way. During the RETRIEVE stage, project leaders search for similar cases, whereas in the REUSE and REVISE stages, similar cases can be used to derive and improve the estimate for the problem case.

This paper presents a system that supports practitioners in these stages. First, data used for experiments is described in Section 4.2. Section 4.3 explains conducted experiments used for the feature selection. Finally, Section 4.4 outlines the similarity function used in the RETRIEVE stage to find similar cases as a starting-point, and also to learn recommendations that are suggested. In Section 4.5 we introduce three types of recommendations that are learned from similar projects' data. Project leaders are asked to adapt recommendations or study recommendation details to amend proposed values.

4.1 Estimation Process and Need for Recommendations

From the structured observations that we performed with four project leads (see Section 3), we constructed a list of activities that project leads perform when planning a new project. In the following, we present activities observed at least twice, in a form that shows its analogy to the CBR cycle. The numbers in brackets behind each activity indicate how many of the 4 test persons performed it.

1. *Get informed*: study the customer briefing (4/4), identify required services (4/4), break down requirements into work packages (4/4)
2. *Retrieve*: search for project drafts (4/4), search projects of same client (3/4), search for projects having the same keywords in title and tasks (4/4), ask other projects about similar past projects (3/4)
3. *Reuse*: copy information from matching draft project (4/4) or similar projects where applicable (4/4), start empty project if nothing similar is available (3/4)
4. *Revise*: enter basic project data (4/4), **add positions that the customer did not mention, but that are required by experience** (2/4), remove or set as optional non-required positions (2/4), **check estimated and actual effort and adjust**

estimated effort accordingly (2/4), **adjust positions that are influenced by other positions** (e.g. **project management** (2/4), adjust by strategy, e.g. lower effort to win a project (4/4), **assume higher effort for a new customer** (3/4) **or a customer known to be demanding** (3/4), meet the budget (2/4)

evaluate offer by asking another project lead (4/4), consider total amount for further adjustments (2/4), submit offer to customer (4/4), call customer (3/4), adjust offer after interaction with customer (4/4)

The CBR cycle is very clearly reflected in the observed behaviour and many activities are performed by all project leads.

We have highlighted in **bold font** those activities where our system will hook in to support the process. In summary, the support will need to address four issues: 1) finding similar projects, 2) identifying additional positions, 3) adjusting efforts based on experiences and 4) finding an expert to review the offer.

For issue 1), the observed strategies of the project leads (searching by customer, title and task keywords) have guided our implementation. Similarly, project leads' strategies for issue 3) helped us to derive features and strategies for automatic effort estimation (e.g. new and demanding customers etc.)

4.2 Data Preprocessing and Analysis

A comprehensive data set including over 13'000 conducted projects from the past 8 years was used for this study. As preparation for the experiments and the final system, project data was analysed and preprocessed. During the preprocessing, the following steps were performed:

- Outlier removal: removing projects with an unrealistic actual/estimated effort ratio coming from cross-subsidisation
- Feature creation: generating new features by calculating values from attributes. The new features will be described in Section 4.3 below.
- Text processing: stemming, stop-word removal and term frequency - inverse document frequency (TFIDF, Joachims (1996)) calculation for textual features

Finally, 7'946 projects remained for the following feature selection and usage for the recommendation system.

Related to the project data, job data was available that allowed for more detailed insights regarding estimated effort and effort outcome. Projects consist of

multiple jobs, which were estimated by project leaders and effort was reported by workers.

For example, a project Corporate Design might consist of the jobs Concept, Logo Design, Business Cards, etc. As effort estimation is performed at the level of jobs, recommendations need to be stated at that level to be directly applicable.

4.3 Feature Selection

To allow the system to work for various industries, only data attributes that are domain unspecific were considered in the feature selection. In the prior pre-processing part, several features were suggested. To prohibit the final system from over-fitting due to too many features, most meaningful features were selected based on project leads' strategies (see Section 4.1). These features were evaluated by comparing the output of different regression-based feature weighting algorithms (CfsSubsetEval, ReliefAttributeEval) and decision tree (M5P, REPTree) output.

The experiment was set up so that all features were used to learn the regression for effort estimation, whereas actual effort outcome was used as solution. The accuracy of the decision trees could be compared to the baseline (Zero-R) values performing a 10-fold cross validation.

Table 1: Effort prediction accuracy (10-fold cross-validation).

	Zero-R	M5P	REPTree
Mean absolute error (MAE)	918.51	205.16	340.63
Root mean squared error (RMSE)	2156.45	670.77	1273.75

Table 1 shows, that learned trees had in average a three times lower error rate compared to the baseline. Highest ranked features are presented in Table 2.

Table 2: Results of feature selection.

Rank	Feature	Type
1	project-size	numeric
2	contact	nominal
3	customer	nominal
4	year	numeric
5	terms	numeric
6	project-leader	nominal
7	job-type	numeric
8	standard-degree	numeric
9	job-amount	numeric
10	divison	nominal
11	new-customer	boolean
12	customer-contacts	numeric

As effective effort is predicted, the project-size (historical estimated costs) allows for a good starting

point to predict effort. Results show further, that customer and contact are key factors in prediction, whereas contact even ranges in one case above customer. Remarkably, despite CfsSubsetEval considering redundancy of features, both features seem meaningful in combination. We can interpret this by acknowledging that certain customers are more demanding than others, and that this depends also largely on the concrete *person* who represents the customer.

Interestingly, the year when the project was conducted is present in all results. Over the years, pricing seem to have changed and thus is considered in the regression calculation to predict effort. Job type and project leader were not selected by all but the majority (3/4) of algorithms.

Terms were available as word-vectors and therefore each as a separate feature. Many of the terms were considered by the regression algorithms. However, the top terms differed in all cases. Thus, for our prototype, the most valuable terms (calculated by TFIDF) in the system were considered. Lastly, the degree of project standardisation was listed in 3/4 outcomes, but scored rather low.

In the final system, the highest ranked six features from Table 2 were used for the effort prediction. They also represent the *problem* characterisation of cases that are used in the Retrieve phase of CBR for the similarity calculation, as described in the next section. The *solution* of each case consists in the set of jobs included in the project planning, together with their respective actual effort.

4.4 Similarity Function

The similarity function is the component in ABE responsible for finding similar cases for the new problem case. For this study, the similarity function is used first in the RETRIEVE stage to serve with projects to use as starting-point and as well in the REUSE and REVISE stages to predict efforts based on regression models learned from similar projects.

Thereby, the feature importance of features can be different compared to the ranks for the effort prediction shown in Table 2. In the similarity function, feature importance is controlled with distinctive weight factors used in the similarity formula shown in Equation 1.

$$\begin{aligned}
 \text{Sim}(p, p') &= \sum_{i=1}^n w_i * \text{SimScore}(f, f') \\
 \text{SimScore}(f, f') &= \begin{cases} 1 - z(|f_i - f'_i|) & \text{if } f_i \text{ and } f'_i \text{ are numerical or ordinal} \\ 1 & \text{if } f_i \text{ and } f'_i \text{ are nominal and } f_i = f'_i \\ 0 & \text{if } f_i \text{ and } f'_i \text{ are nominal and } f_i \neq f'_i \\ z(\text{BM25}(f, f')) & \text{if textual, BM25 similarity score} \\ 1 - z(|\ln(f/f')|) & \text{for project-size} \end{cases}
 \end{aligned} \quad (1)$$

Here, $z(\cdot)$ refers to the minmax normalisation as explained below.

As of Table 2, highest ranked six features were used. Additionally, the feature customer-contacts was chosen as problem recognition has shown that the customer complexity was seen as a major problem by estimators. From a CBR perspective, these features characterise the *problem* of each case, whereas the estimation of effort for the jobs represents the *solution*. For the different types, the similarity is calculated. In case of numerical features, Manhattan distance is used to calculate absolute distance. A special case is shown in Equation 1 for the project-size. As similarity measure for bigger projects should have a broader range, the power-law distribution is converted to a log-normal distribution by applying \ln function. The nominal features contact, customer and project-leader receive a similarity score 1 for identical or 0 if not. Terms used in the feature selection were split into two different features:

1. *title-terms* consisting of main project keywords
2. *job-terms* including terms that describe containing work packages

The similarity score for textual features is calculated by applying BM25 algorithm (Robertson et al., 1995) on the preprocessed terms.

Every *SimScore* is Min-Max-Normalized to have an equal base, ranging from 0 to 1 (Equation 2).

$$z(x_i) = \frac{x_i - \min(x)}{\max(x) - \min(x)} \quad (2)$$

Distinctive feature weights w_i in the similarity function were then assessed to improve case retrieval.

To achieve this, feedback of project leaders was gathered and optimum weights evaluated using an Evolutionary Algorithm (EA). Two project leaders from different domains rated in total five projects: for each of the 5 projects, 100 similar projects were shown, retrieved using the similarity function from Equation 1 with all weights being equal. Resulting answers (similarity = 1, 0, null) and feature scores of similar cases were then used to distinguish optimum

feature weights by maximising Mean Average Precision (MAP) over all presented projects with the evolutionary algorithm.

Table 3 contains calculated feature weights in descending importance, including weight value finally used for the similarity function:

Table 3: Feature weights in descending order of importance for similarity function.

feature	weight
title-terms	0.93789
customer	0.81036
customer-contacts	0.77200
job-terms	0.57435
project-size	0.44832
contact	0.14102
year	0.06006
project-leader	0.00000

The number of customers' contact persons, which did not perform well for the effort prediction, resulted in a very high importance for the similarity function. Surprisingly, the feature *project-leader* received a weight of 0.0 and was therefore ignored in the similarity function.

4.5 Recommendations



Figure 1: A screenshot of a R-1 recommendation.

As the final output of the recommender system, the estimator receives actionable recommendations for the defined problem case. Three recommendations were proposed, based on findings of the problem recognition in the awareness phase:

R-1 Propose Jobs for Addition:

Jobs from retrieved similar projects that are not existing in the new case are proposed to the estimator for addition, see Figure 1. Further, effort is predicted based on found similar jobs. Estimators receive links to related similar projects, to review where those jobs were used (see the link labeled "Also in projects" in Figure 1). This allows the estimator to study similar projects to

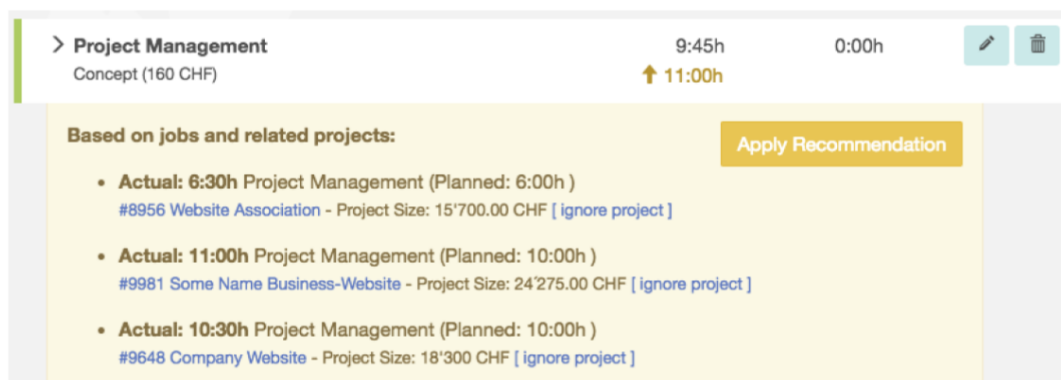


Figure 2: A screenshot of a R-2 recommendation.

decide if the recommended job is appropriate for the new case.

This recommendation was brought up, to (1) support estimators in not forgetting jobs that are necessary and to avoid the situation where they could possibly not be billed later on and (2) to create consistent data so projects are comparable easier to learn from. Observations and the focus group in the awareness phase had shown, that these two problems are main drivers that can lead to non-billable hours.

R-2 Propose Effort Adjustments:

Jobs from retrieved similar projects are mapped to existing jobs of the new case to predict effort for each new job. This mapping is accomplished by comparing terms and job-type. Features presented in Section 4.3 and effort outcome of mapped similar jobs are then used to predict effort for each job in the new case.

For effort prediction, Support Vector Regression (SVR) was used. SVR was reported in studies to outperform alternative algorithms such as linear regression and radial basis functions neural networks (RBFNS) at effort estimation in software projects (Oliveira, 2006; García-Florian et al., 2018). In addition to the predicted effort, the system shows similar jobs and related projects that allow the estimator to study historical effort outcomes, see Figure 2. This recommendation can support estimators having lack of experience for that case (experience with customer, domain or type of work), but also to learn from prior conducted projects in general.

R-3 Propose Reviewers:

Most frequent project leaders from retrieved similar projects are proposed as possible 4-eye reviewers.

4-eye reviews were found in the awareness phase to be often conducted in companies, whereas not

institutionalised. This can help to gain knowledge of project leaders with different experiences and/or skill-sets (e.g. knowing customer, domain, type of work or soft skills).

Along with the interaction possibilities to review and accept these recommendations, two supplementary interactions are offered.

A project-size slider allows the estimator to approximately define an overall project budget. As the system works iteratively and retrieved projects are re-evaluated on any change in jobs (effort change, add/remove jobs), predicted efforts could be volatile. This could confuse estimators and reduce trust in the system. The project-size slider therefore stabilises stated recommendations.

Further, the estimator may identify retrieved projects as not similar to the new problem case. The second interaction possibility therefore allows to ignore such projects for all recommendation computations (see the links labeled “ignore project” in Figure 2). Again, being able to control the input that the system uses e.g. for regression should increase the trust in the outcome and the quality of the result (assuming that humans are effective in excluding non-relevant / non-similar projects).

5 EVALUATION

5.1 Experimental Setup

The aim of our evaluation was to gain qualitative insights – under realistic circumstances – into how project leads would react to the automatically provided recommendations. That is, we wanted to a) understand reasons for adaptation or non-acceptance of recommendations and b) the accuracy of the resulting cost estimates.

We conducted our field experiment in a company that offers mainly two types of services, namely a) design (of e.g. logos, corporate identities etc.) and b) creation of web solutions. In the following, we will call the corresponding divisions “design” and “online”. For our experiment, we selected one senior and one junior project lead from each division to reflect the influence of various experience level on estimation outcomes.

We then chose two historical projects, one from each division. To study also the influence of project complexity, we chose a rather standard project for the online division and a more non-standard project in the design area. The projects were ones that had been conducted by the senior participants some years ago – in order to conceal this fact, the attributes customer name, contact person and address were replaced with fake values. However, we did provide information about cost overruns caused by the respective customer in earlier projects. Of course, the fact that projects were real means that both the historical effort estimates *and* the actually required efforts were known in advance.

Table 4: Summary of test cases in terms of involved project leads (PLs) and area / complexity of the presented project.

Test case	PL	Area	complexity
1	junior design	design	non-standard
2	senior design	design	non-standard
3	junior online	online	standard
4	senior online	online	standard

Table 4 summarises the characteristics of our 4 test cases.

For each test case, we performed a structured observation as follows:

- The test person (TP) received information about the case in a written form, describing the customer’s needs and main characteristics.
- The TP was then encouraged to enter some search criteria to find similar historical projects. It was then left up to the TP whether to choose a retrieved historical project and adapt it or whether to create a new empty project.
- TPs interacted with the new effort estimation system, receiving recommendations. They were able to accept, adapt or reject recommendations and to e.g. mark certain projects from which recommendations were derived as irrelevant (see 4). The behaviour of TPs in this phase was closely observed; when necessary, the researcher asked questions to understand choices or unexpected behaviour.
- When TPs stated that they were satisfied with the derived estimates, a final interview was conducted

with more general questions about how they perceived the help of the system.

Final estimates of TPs were compared to both the historical estimates and the actual outcomes, using the popular regression metrics mean absolute error (MAE) and root mean squared error (RMSE). In addition, we also report the absolute total difference between actual and estimated effort. MAE and RMSE use the squares of deviations – errors cannot cancel each other out and large errors tend to have more weight. Thus, they focus on the ability of the whole system to make accurate estimates on the level of jobs. On the other hand, the absolute difference allows us to gain insight into the absolute deviation and whether it was positive (effort estimated too low) or negative for the whole project.

5.2 Results and Discussion

In the following, we first present our qualitative findings from observing test persons’ reactions to the various recommendations. We then summarise the archived accuracy of cost estimates.

We first observed that one test person (TP) from the design area decided to create an empty project after the retrieval phase: he was not able to find a sufficiently similar historical project to start from. All other TPs did find a historical project and decided to use it as a basis for the new one.

Table 5: Summary of test persons’ reactions to recommendation R-1, comprising the starting point for the creation of a new project as well as the number of job recommendations accepted and the number of jobs in the final offer.

Test case	starting point	#jobs added	final #jobs
1	empty project	2	4
2	similar project	3	4
3	similar project	1	9
4	similar project	1	9

Regarding the acceptance of R-1 recommendations, Table 5 shows that the less standardised design project (see Section 5.1) led to the acceptance of more recommendations (2 and 3 out of 4). In test case 1, these were added to the empty project. In test case 2, it turned out that many positions of the chosen similar project were irrelevant and had to be removed, before the R-1 recommendations were added. Hence, it might have been easier for TP2 to start from an empty project, too.

For the more standard online project, the similar projects chosen as a starting point contained already most of the needed positions, which made R-1 recommendations less relevant. However, both TPs confirmed that the one position they added was meaningful

and hence having R-1 recommendations makes sense also for this case.

A problem that we observed a few times was that R-1 recommendations were considered irrelevant because of their wording and/or scope. For instance, some project leads of historical projects had combined two tasks (say, e.g., A and B) in one job which others had split into two. Thus, when e.g. a project already contained a job for task A, the TPs would hesitate to accept a recommendation to add a job combining A and B.

Another observation was that participants (especially the junior ones) did make use a few times of the possibility to mark a whole project as irrelevant to prevent R-1 recommendations based on it. They remarked that this helped them to get better recommendations.

Regarding the acceptance of R-2 recommendations, Table 6 shows, for each test case, for how many of the job positions the test persons received a recommendation and how often they accepted, modified or ignored that recommendation. In cases where no recommendation was made, the system did not find enough similar jobs in the case base.

Table 6: Summary of test persons’ reactions to recommendation R-2: for how many job positions did test persons accept, modify or ignore the recommendations? How often did they not receive a recommendation?

Test case	accepted	modified	ignored	no recommendation
1	1	1	0	2
2	1	1	0	2
3	0	4	3	2
4	1	4	2	2

We can see that TPs either considered the proposed effort adaptations correct and followed the recommendation. Or, they were not convinced – usually, they would then look at the details, i.e. the jobs from similar projects, to understand the recommendation better. Often, they would conclude that only a subset of these jobs were actually relevant and would thus compute a final estimation as a rough average from this subset. Hence, a feature to exclude irrelevant items also on the job level was found to be missing. In comparatively few cases (and only for the online case), recommendations were completely ignored.

In most cases, the derived estimates followed the tendency of the initial recommendation. For the design case, these tendencies turned out to be correct for 2 out of 2 recommendations, for the online case, the tendency was correct for 5 out of 7 recommendations.

Three additional observations were made:

- **Changed Jobs:** The definition of some job types had changed over time, sometimes based on explicitly communicated rules, leading to significant adjustment of efforts. In such cases, jobs executed according to the outdated rules led to wrong estimates. The most viable solution would be to remove these jobs from the case base.
- **Lack of Trust:** we observed that estimators often adjusted recommendations because they did not trust the system – and this often led to lower accuracy. TPs stated that they expected trust to increase when working with the system for a longer time.
- **Information Overload:** while TPs were effective in assessing the relevance of similar jobs, they were sometimes overwhelmed by the high number of them. Since they saw that some proposed jobs were irrelevant, they felt the need to assess all jobs, which was sometimes too tedious. Obviously, this could also be mitigated by building more trust.

Overall, TPs found R-2 recommendations very helpful and transparent. The possibility to gain insights into the estimations of other project leads was mentioned as a particularly positive side effect of that transparency. Another observed advantage of transparency was the fact that TPs took the time to study similar jobs and thus did not rush to estimations without giving them thorough consideration. Thus, transparency can be argued to support human learning.

R-3 recommendations were hardly found very interesting – TPs stated that they’d know quite well whom to ask for a review. This is not surprising given the small size of the analysed company.

Overall, i.e. across all recommendations and tasks, we could observe that junior project leads relied more heavily on system recommendations and invested more time to study similar projects and jobs to derive their estimates. They also interacted more e.g. to remove non-similar projects and thus improve the accuracy of system estimates.

Finally, we discuss the deviations of estimations from the actual effort, as presented in Table 7. For each test case, we have defined the estimates that were originally derived (i.e. without the help of our tool) as a baseline.

We can observe that improvements were rather clear in the online case whereas the design case results are inconclusive as to whether the new approach will help to improve estimates. Making such conclusions is anyway hardly possible with such a small sample,

Table 7: Summary of test persons' estimates and their deviation from the actual effort incurred in the original project. The baseline refers to the effort estimation that was done without tool support before the project started. Improvements over the baseline are marked in **bold**.

Test case	Estimated effort	Total deviation	MAE	RMSE
1 (junior design)	40	-13	3.375	5.715
2 (senior design)	32	-21	5.250	10.132
Baseline design	41	-12	3.625	6.654
3 (junior online)	148	13	4.944	7.038
4 (senior online)	212	-14	6.333	7.741
Baseline online	81.5	-53.5	6.833	10.446

given also the fact that the deviations between all estimates are substantial.

What we could observe qualitatively though, but what also shows up in the data of Table 7, is the tendency of junior project leads to interact more with the system and to trust more in it. Specifically, they invested the time to remove dissimilar projects to gain a better basis for automatically derived recommendations. In test case 3, this helped to estimate effort for two large job positions more accurately. Senior project leads, on the other hand, were the ones who expressed their lack of trust and hence relied less on the system. Overall, they achieved a lower accuracy in both cases (although the difference is rather small for the online case).

We can thus carefully conclude that an “appropriate” use of the system – which involves making use of the possibility to examine and adapt similar projects and jobs and then trusting the resulting recommendations – will improve estimates in the long run. However, this needs to be investigated more closely in future work.

6 CONCLUSIONS

In this work, we have introduced a novel paradigm for supporting project leads in effort estimation. Our method supports the whole offer creation process: it helps to find similar past projects to use as a basis for a new project, it recommends additional jobs, helps to adjust effort estimations of chosen jobs and suggests knowledgeable colleagues as reviewers. The system explains every recommendation by giving insight into the characteristics of the underlying similar projects and the jobs they contain. It also allows users to give feedback by removing projects that are considered irrelevant. Thus, project leads can better understand and influence the automatically derived recommendations or even just use the provided information for making their own estimates.

Our evaluation has shown that besides component c), all recommendations were considered very helpful by the test persons. Although they were not always

accepted, the offered explanations were heavily used and especially junior project leads also used the possibility to remove irrelevant projects.

We were also able to conclude that, with an appropriate level of trust in the system and by using its feedback features, effort estimation is likely to become more accurate and human learning will be better supported.

We also found a few problems that deserve more investigation in future work: for instance, we found that recommendations of additional jobs could be problematic because of their scope overlapping with the scope of already chosen jobs. Obviously synonyms and ambiguous terms are a challenge for title-based similarity estimation, which should be addressed in the future. Furthermore, although the provided explanations were considered helpful, their number sometimes resulted in a slight information overload – one may have to invent a smarter way of arranging them. Another desirable feature would be the possibility to remove irrelevant items also on the job level. Finally, another issue that we consciously excluded from our study, but which deserves attention in the future is the role that the different possible expertise levels of project members may play in deriving accurate estimates.

Overall, we found that, even despite the system's transparency, especially senior project leads exhibited a lack of trust in the system (which resulted in less accurate estimates), but stated that this might grow over time. Therefore, a more long-term evaluation of productive use of the system shall be performed in the future.

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