The creation of a research model for estimation

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Published: 01/01/1991

Document Version
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

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Download date: 27. Dec. 2018
The creation of a research model for estimation

door M. Howard

Report EUT/BDK/47
ISBN 90-6757-051-6
Eindhoven 1991
THE CREATION OF A RESEARCH MODEL FOR ESTIMATION

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The creation of a research model for estimation / door M. Howard.
Eindhoven: Eindhoven University of Technology.
Department of Industrial Engineering and Management Science.
(Report EUT/B DK; 47)
Met literatuuropga ve.
ISBN 90-6757-051-6
Trefw.: softwareprojectorganisatie/flexibele produktie-automatisering.
INTRODUCTION

Successful software cost estimation (SCE) is a task which can be accomplished in numerous ways. As with many complex problems, it is often difficult to find the "optimal" solution. Rather, an acceptable solution or solution set can be utilized to satisfy the problem. The goal of the current research and this paper is to investigate the reasoning processes used by those who perform software cost estimations. The reasoning processes of the estimators can then be transformed into a research model which will combine all of the strategies used to make an estimation. The two methods in which this aim was accomplished were a questionnaire and a series of interviews. This paper will inform the reader about the results from a questionnaire that was distributed during the European COCOMO Conference as well as the results derived from the interviews between the experimenter and the software cost estimators. The results that were yielded via these two techniques were used to form the current research model.

Because of the complexity involved in a SCE, it was decided by members of our research team at the Technical University of Eindhoven, to approach this investigation via two different angles. The first angle, the interviews, which were between SCE experts and the author of this paper, were necessary to pursue in order to obtain an understanding of what the people whose jobs are largely comprised of making estimations actually do when performing their task. These people are closely involved with the estimation procedure by acknowledging and utilizing the factors that will affect their estimation. These estimators typically have a "good feel" for their project domain as well as the hands on knowledge that is learned when making many estimations. Many of these estimators have also been trained in different estimation techniques and they themselves know the advantages and pitfalls of utilizing one technique over another. The second angle that was used was the questionnaire technique. The questionnaire was meant to be distributed amongst people that were primarily of the non-expert type yet have had some experience with the estimation procedure. There were, of course, some estimators at the European Cost Modelling Conference that could be considered experts (because of their knowledge about the subject as well as the number of projects they have estimated), but the majority of the respondents were not of the expert type. The purpose of the questionnaire was to try and confirm the results from the expert's interviews. The questionnaire provided us a means for double checking the findings of the interviews while
also adding an opportunity to show possible differences between the sample populations. The questionnaire also contained several questions which were specifically designed to aid the researcher in the interpretation of a few answers that were given by the experts during their interviews. It was the hope of the author and of the research team here at Eindhoven, that these two methods would complement one another and provide the missing pieces that one method, stand alone, would contain.

Once the missing pieces are accounted for and all of the possible strategies and techniques of estimating are enumerated, it is feasible to construct a research model of estimation. This model will illustrate all of the cognitive paths an individual can follow when he/she performs an estimation. In addition, each action that is executed on a particular path can now be further broken down into its information processing components. If such an analysis is performed on a detailed cognitive level, understanding the errors that estimators incur starts to become more apparent. If the error analysis points to several cognitive deficiencies or biases, as being the culprit for a poor estimation, a more accurate remedy can be applied to improve the situation. Furthermore, once these local areas of difficulty are discovered, better information or new techniques can provide the necessary help to eliminate the problem. Once such technique that is currently being researched at the TU Eindhoven is the application of a group during the estimation task. This and other techniques will be briefly touched upon in the upcoming sections, but to elaborate further on them is not the focus of this paper. The next section describes the interview procedure, the research team’s expectations of the interview and the results.

THE INTERVIEW

Methodology

Participants- The participants were selected by way of their reputation and position within their companies. Initially, they received a telephone call explaining the purpose of the interview to see if they were interested. Then, the information packet containing the introductory letter (which explained the purpose of the interview) case description and sample questions was sent to each of the participants. The introductory letter also stated that the interview would be tape recorded and the answers to the questions would be kept confidential. Most of them had a week or more to get acquainted with the case description if they liked. It was not mandatory that they spent a designated time period studying the material, however,
familiarity with the case was encouraged. After that, a follow up phone call was made to see if they wanted to participate and to schedule an appointment for the interview. The participants were 12 males working in Dutch firms. The firms varied from consulting companies consisting of one to five people to companies which had about 2000 employees. It was agreed upon that the interviews would be conducted in English. If the subjects had difficulty with a word or phrase, they would be permitted to explain it in Dutch.

Procedure - After the subjects were familiar with the case, the experimenter visited the participants (all but two) at their own offices. The other two participants decided to have the interview at the TU in Eindhoven. Initially, the interviewer asked the subject if there was any information that was unclear and needed to be clarified before the interview started. If there were comments, they were made most often about the fuzziness of the case description. The interviewer would ask that specific comments should be saved for the actual interview. If there were no further questions, the interview proceeded. The start of the interview came when the interview turned the tape recorder on.

The interview could be considered a semi-structured one in which there was a set of questions to be asked in a general format but depending on the answers provided by the participants, ordering and slight rephrasing of the questions were possible. For a complete listing of the questions and the responses, see Appendix A. Please note that the questions relating to cost drivers function point analyses, and analogy were only asked if the subjects themselves had mentioned that they were using these techniques. The reason was that the interviewer would not bias the subject into stating that a particular estimating technique was used when in fact it was not. Quite often, the participants in an interview try to please the experimenter by telling him/her what they think the interviewer wants to hear. Usually, the participants are completely unaware that they are doing that. Therefore, this and other measures were taken to avoid bias. If there was an issue that the interviewer was still unclear about after the participant explained it, the interviewer would try to rephrase the question in a slightly different fashion in hopes of triggering a new angle from the subject. If after several attempts, the interviewer still was confused over a subject’s answer, the question was dropped. The interviewer was careful not to put words into a subject’s mouth even if the interviewer knew what the participant was trying to say but was struggling; perhaps due to the fact that English was not the subject’s native tongue. The interviews lasted between one and a half hours to three hours maximum.
Explanation of the questions

The intent of the questions that were asked during the interviews, tried to uncover several categories. The first was a validation of the type of individual the experimenter thought was participating and his/her relation to estimation. These questions were labelled demographic questions and tried to make clear how many years of experience in estimating and/or project leading the participant had. Also, these questions focused on the individual’s working environment and in what capacity they interacted with it. These questions provided the interviewer with a flavor of the organization (size, positional hierarchy, amount of freedom the individual has and the scope of the software development activities). The second set of questions that was asked had to do with the case description that the researcher requested the participants try to estimate. The case involved a new information system to be developed for a large bank. The functions that the new system had to execute were not extremely detailed in the case description therefore making it difficult if not impossible for most of the participants to estimate. Most of the questions in this category were disregarded in the analysis, but will be briefly explained in the methodology portion of this section. The third set of questions consisted of inquiries related to the participants’ working situations and how they estimate in practice. Lastly, the fourth set of questions queried the participants about their ideas for group intervention during SCE. These group questions were primarily asked to obtain ideas and insights about future research, although many of the participants’ answers also helped uncover additional reasoning strategies. The next section discusses what results the experimenter hoped to obtain.

Expectation of the participants’ answers

Several informal hypotheses were formed about the nature of the participants’ answers. For example, it was thought that the organization or type of organization would have an affect on the strategy used by the estimator. Another hypothesis was: the level of experience of the estimator might also dictate which strategy is employed. It could be quite possible that people that are fairly new to the estimation field might be learning more modern techniques of estimation - e.g. with a computer model of function point analysis. Still, there are others who prefer to use more traditional estimation techniques such as bottom up estimation and train their new estimators in the same thinking.

The experimenter also had expectations regarding the answers given over the case description. It was known beforehand that the case description for the functionality of the
system to be built was written in gross terms. There was little information regarding the functional specifications or the design of the system nor was the information completely clear. It was assumed that the participants would probably have difficulty providing the experimenter with an estimation of the total effort involved for building the system, due to the lack of detail from the case.

Results

Observations during the interview - After sitting through approximately 24 hours of interviews (non consecutively), certain observation of the subjects became evident. Actually, a few of these observations were an obvious pattern after the third or fourth interview. The first most obvious one was the blatant rejection of the case study from the participants. Every subject spoke of the difficulty in understanding how the functionality was supposed to be achieved for the system. The majority of the subjects were reluctant to commit themselves and provide an estimate for the experimenter. The participants could have guessed at the estimation if they wanted to, at no cost to their job or reputation. Yet, even with this assurance, most of the participants did not feel comfortable enough to venture a guess. The second observation also was concerned with the case description estimation. Quite often, the interviewer was asked, "How did the other estimators do it?" or "What did the other estimators get for their answers?" Again, a similar theme as the first observation prevails which is uncertainty but a new theme also emerges which is seeking the input of others to confirm hypotheses about the system status. The third observation of the interviewer was that there were different strategies between organizations as to the proper way of making an estimation. Many organizations had some form of a protocol in terms of system development and the techniques utilized to make a reliable estimation. When the subjects were asked if they would recommend a different technique of estimation or improve on the technique they were using, the overwhelming response was, "no". It seemed curious to the interviewer why with so many techniques of making an estimation, the estimators were content with their own organization's policy. All three of these observations appear to be very "group" oriented in one form or another and will be further commented on later in this paper.

Tabulation of the interview - Because of the free format of the interview, many of the questions were deemed unimportant by the experimenter. This fact was due to the lack of relevancy of some questions as they pertained to the participant's estimation strategy. Many participants said they utilized a particular strategy. Yet, when they explained it were not
completely clear. Then, as mentioned earlier, the interviewer often had to ask the question in a slightly different fashion. This often made certain questions incomparable. There were other questions that after hearing the replies did not seem particularly interesting as was originally thought. Therefore, they will not be mentioned in this report. The questions that did have relevancy to the study are given below in Table 1. Six questions' responses were tabulated across the twelve participants. Under each of the categories within each question are the numbers from 1 - 12 representing subject numbers 1- 12. Since the subject order was assigned randomly, these numbers have no real meaning in the analysis, they are merely for identification. The numbers in the parentheses count the total number of participants in a particular category. The purpose of this table is for the reader to see the distribution of the subjects’ responses across the questions (between subjects). The obvious analysis is to look at each question and see what the spread of answers was. While this information is interesting, one must not forget to compare the same subject across questions (within subjects).
Table 1: Tabulation of Interview

<table>
<thead>
<tr>
<th>1) In what size company do you work?</th>
<th>Small- less than 30 people, or small consulting company</th>
<th>Large- over 30 people in immediate contact or working group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1,2 (3)</td>
<td>3,4,5,6,7,8,9,10,11 (9)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2) What percentage of your job is estimation or related activities?</th>
</tr>
</thead>
<tbody>
<tr>
<td>over 40%</td>
</tr>
<tr>
<td>2,3,4,5,6,7,9,11 (8)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3) For what purpose is the software at your job being developed?</th>
</tr>
</thead>
<tbody>
<tr>
<td>in house</td>
</tr>
<tr>
<td>9,12 (2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4) How many years of related experience do you have?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 4 years</td>
</tr>
<tr>
<td>4,11 (2)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5) Which is your primary technique that you use?</th>
</tr>
</thead>
<tbody>
<tr>
<td>FPA</td>
</tr>
<tr>
<td>3,4,7,10,11,12 (6)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6) Do you believe a group can estimate better than an individual?</th>
</tr>
</thead>
<tbody>
<tr>
<td>yes</td>
</tr>
<tr>
<td>1,3,4,5,6,8,9,10 (8)</td>
</tr>
</tbody>
</table>

Table 1 illustrates that the majority of the subjects came from companies larger than 30 people and more than half of them performed estimations and controlled projects more than 40 percent of their total working time. Half of the respondents said that they developed software for commercial purposes, while the other half either developed software for in house purposes, both inhouse and commercial purposes or did not actually work on the software development but consulted on the planning of the software development. There were only two subject who had less than five years experience. Everyone else had between 5 and 25 years of related software experience. There seemed to be a split between the primary estimation technique utilized by the subjects. Half of the subjects used the Function Point Analysis (FPA) as their primary methodology for estimation, 5 subjects utilized the bottom up technique (breaking the activities down into known measurable pieces then adding up the
durations of the activities) and 1 subject used a top down approach, similar to FPA but used modules as the lowest common denominator instead of function points. Lastly, the subjects were asked the question, "Do you believe a group can estimate better than an individual?" Eight out of 12 participants said, "yes", 3 were "unsure" and 1 said, "no".

After pairing 2 questions together, new insights become apparent. For example - if we look at the experience level of the subjects and their responses to whether they believed a group can estimate better than an individual, we see that all of the participants that had experience of more than 10 years in the field also felt that a group can estimate better than an individual. Another pairing of questions includes out of all the people that used bottom up analysis, 80 percent of them had more than 10 years experience. In addition, 86 percent of the people who used FPA or the other top down technique had less than 10 years experience. This would indicate that the more experienced estimators used the technique that was originally taught to them rather than switching to a newer technique. This choice might or might not have been a conscious one. Similarly, the less experienced estimators could have done the same - that is stick to the technique that was originally taught to them (FPA), yet the technique happens to be more modern. Or the less experienced subjects might have consciously chosen the newer techniques due to their willingness to try new methodologies. However, clarification on these questions was not obtained.

Table 1 was derived from the participants’ answers and their understanding of the system which has been documented in Appendix B. This appendix briefly summarizes each one of the subject’s responses in a few sentences about how they proceeded with their estimation. These descriptions later became the basis for the research model which will be discussed in later sections.

The link between the interview and the questionnaire

The answers on the questionnaire helped the experimenter during the analysis phase of the interviews. For example, the questionnaire indicated that many estimators use more than one strategy and/or technique before the final estimation is specified. This factor plays an important role in the research model’s development as well as understanding why some people do a combination of several techniques. The questionnaire also indicated that estimators are very dependent on the strategies they employ and feel that their success is based on them. This information could indicate that estimators do not often deviate from their established schema regardless of the domain. Each individual more or less seemed to follow
one "path" or thought process when approaching an estimation problem. This at least indicates consistent behaviour within people.

Lastly, the questionnaire confirmed several hypotheses about group intervention for SCE. These issues will be discussed in the next section but here it will suffice to say that the questionnaire responses supported overwhelmingly what the majority of the people that were interviewed said, "Incorporating a group into SCE improves the accuracy of the estimation as well as provide organizational benefits".

THE QUESTIONNAIRE

As mentioned in the last section, the questionnaire's purpose was to ask a different population of estimators similar questions as the interviewees, from another perspective. It was the hopes of the experimenter to show confirming evidence of the interviewees' responses as well as determine if there existed any differences between the populations queried. The questionnaire also helped the experimenter with her analysis of the information processes used by the estimators which will be discussed in the next section. The following subsection describes the methodology of administering the questionnaires.

Methodology

The querying took place at the European Software Cost Modelling Meeting in June of 1991. The conference's location was in the Netherlands and the 75 participants came from European countries as well as a few from the U.S. The conference attenders were from academia, industry and/or government positions. Most of them had an interest in SCE. Some of these individuals estimated software costs as a regular part of their job. Others occasionally performed estimations. There were no other demographics known about the participants.

The questionnaires were distributed during the second day of the conference. They were passed out to all of the participants sitting in the room at the time, (about 50 people). The participants were asked to fill in the questionnaire at their leisure and return it to the experimenter by the next day which was the end of the conference. Thirty-six people returned the questionnaire back to the experimenter but only 29 questionnaires were used for the analysis. The other 7 questionnaires were not filled in properly - they were merely commenting about the types of questions being asked or asking for further professional contact with the experimenter. As a result, the sample population was 29. This number must be kept in mind when trying to count the responses for a particular question on the
questionnaire. The entire questionnaire and its associated responses for each question is found in Appendix C. Certain responses have numbers next to them. This indicates the number of people that responded in the same way.

**Results of the questionnaire**

If the reader wishes to review the exact responses to the questionnaire, he/she can refer to Appendix C, yet the questions and their responses will also be discussed in this section. The first question asks the respondents to check the strategies that they regularly use to perform an estimation. Many participants selected more than one approach. Yet most of the respondents used the technique of breaking down the project into smaller more manageable pieces and then comparing the project with another one which had been estimated in the past.

The interview question of particular interest asked the subjects to describe the course of action or thought process employed when performing an estimation. Then, the experimenter inferred from their responses which strategy was used. If the subject was not entirely explicit, other questions were asked with a different angle. The question that was asked on the questionnaire was phrased slightly different then the one asked in the interview. The question that appeared on the questionnaire asked the respondents themselves to categorize their behaviour or strategy that they utilized. It should be noted that many people perceive themselves as doing a particular action when in reality they are doing something else. Therefore, the experimenter is cautious to weight heavily the results of the questionnaire for these types of inquiries. It was also interesting to note in the first question that 41 percent of the respondents did use function point analysis as one of their strategies as compared with 50 percent of the people that were interviewed. That difference is not substantial given the small sample sizes. Also, all of the respondents in the questionnaire responded that they employ breaking down the project into smaller more manageable pieces. This strategy appears to be applicable in many situations. Although, the time required to perform such an estimation using this technique is perhaps the reason why this might not be everyone’s primary technique.

When poled whether estimators can still make an estimation without using a technique, 13 people said, "no", 11 people said, "yes" and 5 did not respond. They were then asked if they felt the accuracy of their estimation depended on the strategy/technique that they employed, 24 said, "yes" and 4 said, "no". When asked if they can use their strategy/technique for any estimation problem in any domain, 17 people said, "no", and 12 people said, "yes".
It seems from these responses that people have their own way of making estimations that they are convinced will bring them success and they feel insecure if they can not use their techniques.

There were several organizational questions that appeared on the questionnaire. The first asked if type of organization and its climate (authoritative, participative, etc...) contributed substantially towards the outcome of the estimation. Eighteen people said, "yes", 4 people said, "no" and 7 people said, "not applicable". There were two questions that inquired about the differences between European countries and/or organizations versus America and its companies, but will not be elaborated in this report. It was asked whether the individual normally worked in a group or sought the advice of others when performing an estimation. There were 23 people that said, "yes" and 3 people that said, "no". Also, the same question that was asked in the interview, "Do you think a group of people in general is capable of making a more accurate estimation than an individual" was asked on the questionnaire. Nineteen people responded "yes", 3 people responded "no" and 6 people said, "not applicable". These responses appeared to be consistent with the interviewees' support for a group approach to estimation. Seventy-five percent of the interviewees said that a group is more capable than an individual of making an accurate estimation as compared to 66 percent on the questionnaire. However, the difference could be due to small sample size.

Lastly it was asked, "How would you improve SCE in general?" But the various answers to this question will not be discussed here. Again, see Appendix C for a complete listing.

Implications of the questionnaire

The questionnaire confirms, via responses to several of the questions, the basic premise of the research which is to obtain a grasp for the estimation process. The respondents of the questionnaire have explicitly stated that they believe a group is more capable of making a better estimation than an individual and furthermore specify that the accuracy of the estimation is dependent on the strategies or techniques employed. These two points leads one to believe that developing a strategy for estimation within a group framework is definitely in order.

First, one needs to recognize the possibilities for a group in SCE and the next step becomes to restructure the estimation task to include a group. Before the group can be applied, the estimation task must be made explicit in order to clarify activities which might
or might not be relevant to the task at hand. A model of an individual’s thought processes while he/she makes an estimation is the first step in understanding the task at hand. The next section does just that. The next section is an information processing approach to analyzing the estimation task and presents to the reader a descriptive model derived from the interviews.

THE RESEARCH MODEL

An information processing approach

Why use an information processing approach for analyzing the estimation task? The answer is fourfold: 1) to see what kind of knowledge is needed to perform the estimation in general and at various stages in the information processing; 2) to identify the possible problem areas or errors that might arise while performing the estimation; 3) to classify these errors into their cognitive components; and 4) to specify places in the model for improvement. Once these factors are accomplished, it is then possible to reformulate the estimation task within a group setting.

An information processing approach to error analysis is a technique that has been used by psychologists for years and is now making its presence felt in the field of cognitive engineering, (Johanssen, 1988, Carnino, et al., 1988, Swain and Wetson, 1988 and Fisher, 1981). The technique involves dividing the task into smaller elements such that it may follow an information processing flow diagram. For example, if a functional requirement is to be utilized to build an information system, it must first be read or perceived, acknowledged, stored in working memory, or long term memory, then retrieved if coming from long term memory and then later used in some sort of evaluative process. Depending on the requirement and the abilities of the estimator, some understanding of the functionality of the system may be lost from working memory unjustly, or reasoned about inaccurately based on a poor understanding of the system to be built.

Figure 1 has been derived from combining the responses of the interviewees, across the question, "What are the steps you take in making an estimation?" Some experts interviewed were practically able to sequentially explain the steps from start to finish. The reader should notice on Figure 1, that there are quite a number of steps or activities one does before arriving at their estimation. There are also many paths to choose from to arrive at an estimation. Some experts chose to follow one path while others chose another. This descriptive model does not specify the "correct" path or even acknowledge the fact that there
UNDERSTANDING THE SYSTEM

Figure 1: Research Model

1. READ USER'S DEMANDS
2. FILTER USER'S DEMANDS

ORGANIZE SYSTEM TO OBTAIN WORKING SYSTEM MODEL

3. MAKE SUBMODELS

--- DATA, INFO. FLOW, FUNCT. DEMANDS, RISK, CONSTRAINTS, RELATIONS BETWEEN ACTIVITIES

GENERATE THE RESIDUAL

ASSESSING SYSTEM SIZE

GENERATE THE RESIDUAL

FUNCTIONAL BREAKDOWN INTO COMPONENTS

FUNCTIONAL BREAKDOWN INTO ACTIVITIES

FACTOR THE RESIDUAL

ASSIGNING EFFORT FOR A SPECIFIC ACTIVITY/COMPONENT

FACTOR THE RESIDUAL

MAKE A RISK ANALYSIS

FACTOR THE RESIDUAL

ASSIGNING EFFORT FOR # OF SCREENS/MODULES
exists one right way to perform an estimation. Figure 1 merely enumerates all of the possibilities that were discovered in this field study of expert estimators.

In Figure 1, there are two types of boxes. Once box is a solid box with straight borders and the other box has jagged edges around it. The solid box represents explicit action items the estimator is aware of. These action items are usually obvious and identifiable and can be explained to others somewhat easily. The jagged box signifies fuzzy action items or stated another way, these actions are not obvious to the estimator who is making them nor can they be well explained to others. Many times the estimator would describe these fuzzy actions as, "A feeling he/she has about the system to be built". Or, these fuzzy items are the insight that the expert possesses which is difficult to put into words. Call it what you will, these fuzzy actions do exist in this model as well as in most complex task breakdowns. These fuzzy actions will be further explained in the next few paragraphs. The lines with an arrow in the figure represent pathways from one action to the next. Many times there exists more than one path leading out of a particular action. If this is the case, it implies that the estimator can either choose one path or as many paths as do exist. These multiple paths are both and/or options. The horizontal dotted line across the page separates the top half of the model which is the estimator's understanding of the system to be developed and the bottom half of the model which signifies the individual's cost estimation of the system. One should notice in Figure 1, the amount of information given above the dotted line as compared to below it. This implies that it is not the estimation of the system that is so complex and varied, but it is the understanding of the system which has the most potential for error.

Explanation of the model

The following explanation describes all possible pathways a person might take to arrive at an estimation. Each option will be described. The author of this paper advises the reader to keep in mind that at any stage, analogy can take place. That is to say that it is possible that the estimator will compare the present activity of the estimation procedure to something that has been done in the past or a known activity which can relate to the current step.

Starting from the top of Figure 1, the estimator needs to read and/or listen to the user's demands for the new system to be developed. The user will specify such system characteristics as the functionality, constraints of the environment, usability and quality standards. The next step that the estimator must make is to simplify the system demands into
something that is manageable or easy to work with. There are three possible ways to do that as shown in the figure by the three possible paths - 1, 2 and 3. Path 3 is perhaps the easiest to explain, so I will do that first and then work backward. If an estimator is inexperienced with the problem area or type of system to be built or if the estimator wants to explicitly lay out the system in terms of different factors to consider, he/she might choose this path. First the estimator might or might not need to filter some information from the user in order to press onward. The filtering process occurs by a person explicitly acknowledging a chunk of information and either storing it in the long term memory or disregarding the information due to its perceived lack of importance. After the information is in a workable format, the estimator might choose to create any one or all of the possible types of submodels given in the figure. These models would be explicitly represented e.g. on paper or computer so they can be shown to other people. These models can help in the understanding of the system. After the models have been created, the user might or might not generate what I call, the residual. The residual is the left over information that is not being explicitly taken into account. For example, the estimator might have considered all of the functionality of the system but never explicitly factored in the quality standards. It is at this point, if the information has not been filtered that the estimator would either consciously or unconsciously do some "mental housekeeping".

Path 2 indicates that the estimator is going through some sort of filtering process as mentioned before but we do not know how structured it is nor at what level of consciousness the estimator is aware of it happening. Path 1 goes from the user’s demands to a simplified system without having any sort of structured refinement nor necessary consciousness. For example, if an estimator hears the user’s demands and then prescribes a system architecture immediately, he/she might not be refining any information but just having an image of a predetermined system that he/she believes is the answer for most if not all problems. Either one or all of these paths may be chosen by the estimator.

The next action item that must be reached is the process of simplifying the system, to a "working model". The working system model parallels the information processing term "working memory" in which only a limited amount of information is present. Furthermore, the working memory can only manipulate a limited amount of information at a time corresponding to its upper storage capacity limit. Similarly, the working system model can only store the most "relevant" data about the system, the other information is either stored in
the estimator's long term memory or disregarded. It is in this stage that the information that was or was not filtered in previous steps becomes organized. For example, if an estimator's opinion about making data models for a system is that they don't really provide new insight to a situation, and if the estimator was running low on storage capacity, he/she might disregard all information concerning data models of the system. If there was plenty or storage available because other elements of the system were easy to grasp, or familiar patterns emerged from previous systems (thus chunking information together), then information about data models might be either stored in long term memory or brought to the forefront in the working system memory. This mental organization might or might not be a conscious one. Furthermore, if the step is a conscious one, then it does not have to be explicit. It all depends on the estimator, and the level of experience or talent that he/she has in condensing large amounts of information.

The next action item is, again, generating the residual which as mentioned earlier acknowledges the left over variables or requirements that were not taken into account for the working model of the system. If this step was not performed earlier in the understanding of the system, it would most likely be performed at this time. This action is a fuzzy one in the action sequence which might or might not be obvious to the estimator. Yet we know that it does occur because there was always information that the estimators talked about during the interviews, that was not used in the direct calculation of the overall project effort but was utilized in the post estimation procedure. Originating from this fuzzy action point are 4 different pathways.

Pathway A leads to the action item of assessing the size of the system in terms of either the functions needed, lines of code, number of screens needed, modules, or function points required. This assessment is a top down driven action. All of these forms of assessing the system are performed from a holistic system point of view. In this step, functions, modules, etc... are counted and/or the difficulty is assessed via such qualitative terms as "easy, average or difficult". This step requires judgments to be made about the system and errors are often possible in this step, due to its global approach.

Continuing onward from Path A is the actual "estimation" part of the procedure where standard rules of thumb or predetermined units of time are applied. For example, "One difficult function equals 3 units of time" or "This function equals 6 function points". Then, usually once the time to perform the project has been established, the total cost of the project...
follows shortly afterward - usually by another rule of thumb. After the total amount and effort has been determined, the estimator will factor into account the residual that was created in previous steps. For example, "Since our programming department has never programmed in this new language, let's add on another 20 percent to the total time and raise the total cost by 30 percent". It has also been mentioned by some of the estimators, that they would at this point do a risk analysis to determine if there were any factors which might damage the accuracy of the estimation or change the overall understanding of the system. If there were, they would factor these differences into account (usually by a rule of thumb) and modify their estimate.

Pathway B, again, derived from the "generate the residual" stage leads to what is labelled the functional breakdown of the requirements into system components. What this means in the ideal situation is, for every function which is specified in the list of requirements, a system component is devoted entirely to it. Thus, there exists a direct one to one mapping from function to component in the ideal setting. Many times the one to one relationship is difficult to achieve, yet this is the goal that is strived for. It becomes a relatively easy task to debug and maintain a system when for some reason the system ceases to perform a specific function. One merely has to repair the component responsible instead of having to take the entire system apart if the functions were interlinked. From this point in the model, an estimator might choose to include the residual before the estimation is performed. If that were the case, the individual might look at each component which needed to be built and then specify if any of the residual factors might affect it before deciding on the amount of time it takes to build it. When and if the residual has been accounted for, the estimator will assign an effort or time required to build each of the system components. When this action is completed, the estimator has the choice again to factor in the residual (i.e. adding a safety factor in terms of time and cost onto the total estimation) and/or perform a risk analysis - as in the previous paragraph.

Pathway D emanates from the "generate the residual" step and is similar to Path B yet the estimator in this step would convert the functions into specific activities rather than components. For example - if the functional requirements said, "All data must be converted to a specific format and then stored in the database", then this might entail performing activities A, B, and C. In the next step, the residual might or might not be taken into account before the actual estimation begins. The estimation is essentially the same as was mentioned
in the previous paragraph - yet the conversion factor reads like, "It will take 3 units of time to do activity A, 2 units for activity B...". Again, the residual could then be factored in as well as a risk analysis performed.

Pathway C can be essentially the same as Paths, B or D but in this case, the system is not explicitly analyzed or at least is not obvious to the astute observer. Here, the estimator has either the great talent (or luck) of knowing which are the components/activities which need to be accomplished, but does not spell it out as in the other paths. The transition into the estimation stage is a grand leap from functional requirements to calculating each component/activity. After the estimation has been performed, the residual is factored in and possibly a risk analysis is performed. In this section, a descriptive model of estimation was described. The next section briefly explains how a group can mold into the estimation procedure.

The application of a group

As motivated in previous literature, (Howard et al., 1991) the inclusion of a group during the SCE procedure can aid in the accuracy of the estimation by dispersing the high mental workload throughout the members of the group, clarifying unclear factors and reinforcing commitment to the problem from each member of the team. While in theory, all of these statements seem quite logical, putting them to practice is another story. How should we now change a task that is normally performed by an individual to a group task?

It was realized that a good foundation for creating the estimation task to include the group would be derived form the information processing model of the individual. Since there are several paths one might take to arrive at an estimation, it first needs to be determined if there is one optimum path to follow or if most of them provide a good enough strategy to obtain a reasonably accurate estimation. Once this determination has been established, the problem will be made clearer. For demonstrative purposes though, let us select a path on the information processing model (Figure 1) - Path 2D. This path has the following action items - read user's demands, filter specific activities, organize the system, generate the residual, relate functions to specific activities, estimate the activities and factor in the residual. There are several action items on this path which include making judgments about the status of the situation. These judgments pertain to which factors about the system should be utilized and which factors should be filtered out; how the system model should be organized to its simplest and most clear state; which factors or requirements should be put on the "back
burner" and utilized later; and the decision for the amount of effort each activity will take. Each judgment the individually normally encounters will now be attacked by a group.

If the group interaction is synthesized well, the group has the potential of analyzing the system status from many diverse angles which the individual alone can not provide. The group can also deal with large amounts of information at one time to a greater extent than the individual because of the fact that each member of the group can store separate information that the individual would be forced to disregard due to capacity limitations of the memory. The group also has the capability of diminishing if not eliminating decision bias. Often times an individual has a set "script" of approaching a problem and/or estimation. No matter what the functional requirements of the system may be or which staff must build the system, the estimator might not modify the approach towards understanding and/or estimating the system. This bias can be detrimental for the estimation of unique products. Cognitive bias and its implications will be briefly discussed in the next section. Yet, now it is sufficient to say that the advantage of employing a group becomes evident during the judgment tasks. Further research needs to be done to confirm these speculations about when and how to utilize a group for the estimation process.

Cognitive bias and its relationship to mental models

Mental models are comprised of system relationships that were previously acquired by a person as well as the incorporation of new knowledge of system relationships from updated system data. Figure 1, the information processing model - which was a conglomeration from 12 estimators, can be thought of as a mental model if it had been created by an individual. Since Figure 1 has many pathways on it, or many ways of approaching an estimation problem, it would be highly unlikely that an individual estimator would subscribe to all of these pathways. This would mean that the individual estimator would have to utilize all of the paths before offering an estimation. Yet, it could be possible. Realistically speaking, an estimator might have a preference to utilize a particular path and only venture out to other paths if time permits. This preference for a particular problem solving approach can be labelled a cognitive bias.

Moray (1988) states that often pieces of information will be missing from a person's mental model. Moray hypothesized that people do not learn the entire system in a holistic manner, i.e. how all of the variables and factors fit together to achieve a common goal. Rather, they learn reduced versions of the original model in order to simplify the system, e.g.
one path of the system model. These reduced versions are often incomplete because they are simplified subsets of the true system state and the variables or factors which influence it.

Because individual estimators approach a problem from a certain perspective, it is not uncommon for new problems to be dealt with in an old way. This sort of protocol can result in internal biases during reasoning - evaluating the first bit of information received and forming a hypothesis based solely on that. Another problem presents itself when a subject always uses a "canned" answer (e.g. take two aspirin and call me in the morning) without consideration of the actual conditions. Both instances of bias result from deciding on a particular action to take, hence in the cognitive portion of the information processing.

Cognitive bias may stem from high mental workload (Woods, 1989). If the quality of the information is excessive or there exists too little time to process the data, shortcuts might be utilized thus causing cognitive bias. Woods also labeled a common error which occurred in his experiment as, "Significance of Data". This happens when the cognitive demand is to find the relevant data out of a mass of potentially relevant data. This is essentially what an estimator has to do. Woods states that in order to simplify the data, the individual chooses the symptoms he/she understands best and forms a hypothesis based upon them. If new incoming information cannot readily fit into the mental model of the system, the estimator might select the variables which can more easily fit in and use only them, while ignoring the other factors.

It is this sort of bias in SCE which can be abolished if a group is employed for the task. The reason is this: there are many different perspectives which need to be incorporated to make a complex decision such as an estimation. Everybody wants to feel like their input is valued. Consequently, members of the group might be willing to defend their unique position and possibly sway others to their way of thinking. This sort of interaction results in members of the group learning all the different arguments for considering one factor over another, and consequently forces individuals in the group to become more knowledgeable about the big system picture. In this scenario, cognitive bias is diminished through the open communication and understanding of the system that the group provides.

SUMMARY AND CONCLUSIONS

This paper has described both the purpose of the interviews and the questionnaire which was to discover the reasoning processes of software cost estimators and the way in
which they approached estimation problems. This paper gave a descriptive account of the
methodology and the results of both the interviews and the questionnaire, and from the
results, the author generated the research model of an individual performing an estimation.

The research model has now given us a basis for formulating a group approach to
estimation. Future research will determine if there is a path on the research model diagram
which will provide an optimal or close to optimal solution. If there is such a path, future
research will be to discover the best way to accomplish each of these action items along the
path. It is the hope of this research that employing a group for the estimation task will reduce
mental workload for an individual estimator as well as increase accuracy of the estimation and
eliminate cognitive bias.
REFERENCES


APPENDIX A

Questions to Ask Experts

Demographic Questions
1) What kind of company are you working for (e.g. scope of the software development activities, software development staff, number of employees, kind of products, and type of software being produced)?
2) What percentage of your job is estimation or related activities (project leadership)?
3) Are you developing software in house or for commercial purposes at your current job?
4) How many years of related experience do you have?
5) How familiar were you with this type of case?
6) What is the range of effort on projects that you've been working on in the past?

Estimation Questions Specific to the Case
1) What was your estimation of the effort needed?
2) On a scale from 1-5 (1 = not at all confident, 5 = very confident) how confident were you in giving your estimation?
3) Can you explain your methodology or strategy that you used to develop your estimation?
4) What were the factors that you considered for your estimation?
5) Were there factors that you wished you could quantify but couldn't? If yes, how did you incorporate the qualitative data?
6) Did you feel under pressure giving the estimation for this study? Does that differ in your present job situation?
7) Did you feel that this case description could have been improved? If yes, in what way?
8) Was everything clear in the case description? If no, what was not?
9) Did you have all the information you desired to make your estimation? If no, what did you feel was missing?

General Questions about Estimation and Your Working Situation
1) Is this a typical sort of estimation problem you would be asked to perform? In what way does it differ at all from your present situation?
2) Do you wish you could have similar estimation problems like this in your everyday job? Why, or why not?
3) Can you give us a description of how you perform an estimation at work? (you can include the organizational environment, the customer and the people you work with if you like).

4) Do you foresee any shortcomings with your estimation procedure? If yes, what are the potential problems?

5) What is the normal time you are given to perform estimations at work?

6) How would you improve software cost estimation in general?

Cost Driver Questions

1) ... You mentioned that you used cost drivers (factors) when you estimate. How did you use the cost drivers specifically?

2) Are those cost drivers specific to this case, or do you think about them also in your job?

3) Which cost drivers did you think were the most pertinent to the case?

Function Point Questions

1) ... You mentioned that you try to group the work into functional points. How exactly do you do that?

2) Are these functional points specific to this case or do you think about them also in your job?

3) Which functional points were the most pertinent to this case?

Analogy Questions

1) ... You mentioned that this case reminded you of another one that you’ve done in the past. Do you often compare present cases to the ones you’ve done in the past?

2) Do you collect data at work on past projects? If yes, what kind of data are you interested in?

3) How do you use that data on current projects?

4) Do you need to interact with others in order to get help in interpreting the data?

Group Questions

1) ... You mentioned earlier that you consult other people when you make your estimation in practice. Do you believe that a group of people assigned to estimate a problem similar to this one can produce a better estimate than an individual? Why?
... You mentioned earlier that you felt there needed to be a sense of commitment by the involved parties...

... You mentioned earlier that there were a lot of factors, maybe even too many for one person to handle on his/her own...

2) If you could pick any kinds of people for your group, who would you pick and why?

3) If you had the chance to lead and advise the group - would you advise the group to perform the same steps you took in your individual estimation or would you want the group to try something different?

4) Do you think there is something uniquely different about a group performing an estimation over an individual?
Each Subject's Understanding of the System and Their Estimations

1) Subject 1 (S1) - realized demands of new system/made explicit models of information flow, functional demands, constraints and relationships between activities/ took activities and broke them down into subactivities/estimated each activity/ factored in residual.

2) (S2) - realized demands of new system/ filtered "extraneous" info. into the residual/ took activities and broke them down into subactivities/estimated each activity (based on the past)/factored in residual

3) (S3) - looked at non-functional factors (organizational)/ made residual/made a functional decomposition/ got an idea of the size of the project by looking at the data elements/ estimated each activity/ also checked with FPA for relative size if functional specs are present/ factored in residual

4) (S4) - first defined the input and outputs while realizing the demands of the system/ made residual/ specified the functionality/ did a sizing measure for functional fields/ function - activity breakdown/ estimated each activity/ did FPA/ factored in residual

5) (S5) - explicitly acknowledged user’s demands/filtered demands/defined deliverables into explicit activities/ estimated each activity/ cross checked with a matrix which gives rules of thumb for how much effort is spent for each function to be programmed/ factored in residual

6) (S6) - All the things that the system must do functionally are realized/sized the project/ evaluated functions and decided if they are difficult or easy/ did FPA modularly/ added risks/ added residuals

7) (S7) - looked at user’s demands and saw what are the important things to concentrate on and things to watch out for/made a data model/made a model of functional demands/ made residual/"What are the screens we need"/did FPA/factored in residual/cross checked with others performing bottom up

8) (S8) - read user demands/broke down the functional demands into workable activities/estimated activity

9) (S9) - must be a definition study (user demands)/ made residual - risk factors/started counting screens/estimated via X screens = Y modules/price per module/added residual

10) (S10) - must be functional specs/made a residual by doing a risk analysis/ converted functions to function points/estimated price per function point/ factored residual and risk along
with a correction schema from IBM

11) (S11) - must be functional specs/ made residual and noted some risk factors/ grouped the transactions or activities needed to be accomplished into difficult or easy/estimated the function points from that/ price per function point/ factored residual

12) (S12) - looked at functions needed to be done/if there is a risk factor that affects volume, he takes that into account/ determined function points/factored in the "volume" factor that might change the price per function point/ estimated price per function point based on a rule of thumb
APPENDIX C

Questionnaire for Software Cost Modelling Conference

By the Researchers of Eindhoven University of Technology

N = 29

1) Several strategies and techniques for estimating software are listed below. Please check the ones that you regularly use or provide us with additional selections that are not listed.

Strategies and/or Techniques
27 breaking down the project into smaller more manageable pieces
9 using a top down organizational perspective (documentation, integration of system within the company, etc...) for deciding which factors in development have higher priority
15 using a bottom up perspective - composing a complete product from the features or exact functionality that the system should include
18 utilizing the advice from several people
15 seeking the advice of an expert(s)
25 comparing the project with another one you’ve estimated in the past
12 function point analysis
9 price to win (commercial motivations)
22 using a software tool or parametric model
16 determining the important cost drivers of the project
7 modifying data from a previous project
.... other -
-internal cost models
-SSM-PERT
-determining amount of functionality being produced with the available staff in the required timescale
-brainstorming, Delphi, group, analogy.

2) If you checked one or more of the categories above, it implies that you are using a strategy/technique or a combination of them to produce your estimation. Aside from the sequencing of these strategies/techniques is there anything else you incorporate into your estimation?

Circle one: Yes / No / Not Applicable (N.A.)
15 11 2

If yes, what else?
-An analytical approach
-A review process followed by updating the estimate
-the overall personal feeling of myself about the estimation-result after having used the strategies
-risk analysis
-risk management - ranges of values from several models
-training internal consultancy support, centralised tools bureau
-get a second opinion by experts
-timescale technology interfacing with H/W
-rules of thumb e.g. DSI
-process model tailored to fit project framework including role definitions and quality plan considerations
-risk analysis
-process modelling, process engineering, process aggregation, risk analysis
-risk analysis, documentation of the whole process, constant review of project estimate, ensuring the use of at least 2 independent techniques

3) Can you still perform an estimation without using your strategies or techniques? Circle one: Yes / No / N.A.
   11 13  5

4) Do you think the accuracy of your estimation is dependent on the strategies/techniques you employ? Circle one: Yes / No / N.A.
   24  4  1

5) Can you use your strategies and/or techniques for every estimation problem in any domain? Circle one: Yes / No / N.A.
   12 17

6) In your experience, does the type of organization (authoritative, participative etc...) where the estimation is formulated contribute substantially towards the outcome of the estimation? Circle one: Yes / No / N.A.
   18  4  7

7) Do you think there are major differences in the U.S. organizations vs. the European organizations which can affect the estimation? Circle one: Yes / No / N.A.
   8 10 10
   If you answered yes, what are the differences?
   -standards
   -U.S. companies have special departments which evaluate the software engineering process, in Europe, all this work including the methods have to be done by the project leaders themselves
   -Then, every made estimation is only for that project to be realised by that group
   -quality management considerations are taken into account here and not in the US
   -culture, methodologies, productivity, technical support
   -level of authority, individuals vs. group responsibility, managerial competence
   -organization of software teams

8) Are there major organizational differences within European countries which can affect the estimation? Circle one: Yes / No / N.A.
   10  7 11
   If yes, what are the differences?
   technological traditions
   -no unit tests, codes, schedule aspects, size of SW , methodologies, standard process model, experience
   -experience (like East and W. Germany)
   -between military and nonmilitary
   -cultural differences, methodology, management structures
-project - function matrix gives different levels of commitment to estimate
-egoless participation, group technique, management awareness
-education, level of technology
-the influence of MOD 00-55 standards imposition!
-training, culture, expectations especially with respect to individual and group relationships

9) At work, do you normally work in a group or seek the advice of others when performing an estimation? Circle one: Yes / No / N.A.

   23  3

10) Do you think a group of people, in general, is capable of making a more accurate estimation than an individual? Circle one: Yes / No / N.A.

   19  3  6

11) How would you improve software cost estimation in general?
-By calibrating to obtain your own model
-successive calibration until reaching in house model, a knowledge-based approach
-disseminated of experiences, information, and ideas at meetings like this and in the published literature
-by considering cost estimation as an actual project by itself (delay resources)
-depends a lot on organization
-by developing a tool to size data (FPA) directly from a tool-based specification and also having the tool calibrate itself on a range of projects
-standardization methodology, normalization
-automation tools, feedback- databases, statistics
-collect data to improve calibration of parametric models
-capture domain knowledge, include reusability to full extent, learning strategy for calibration
-get organization to adopt or develop an estimation strategy suited to their environment which then needs resources to support its application
-risk management
-be sure that everyone applies the same set of rules and departmental norms. Each realized project has to be evaluated, eventually followed by modification of the norms.
-more structured development process, better requirements analysis
-produce a historical database via a metrics program and prototype instances of great uncertainty
-by installing results of MERMAID project (giving a selection of different techniques
-encourage egoless environment and incentives for accurate estimation. Establish role and relationships with project structure and metrics function. Keep good quality records
-collect more data, reuse more software
-group would enable more effort to be deployed to gain greater understanding but members of the group would work as a "mini project". The resultant estimate would not normally be a mean of the individuals' inputs
-by enhancing quality in SE as requiring cost estimation of a high standard as an integral part of sound professional software management procedures
-create environment domain - but it can be difficult
-model the process. Measure it. QC/QA the process. Integrate the process into the organization (rather than just providing them). Categorize processes (and any tools/methods within them) so that match with the user can be made and so that results of ___ can be used to guide the next action
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