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A subjective effort estimation experiment

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Abstract

Effort estimation is difficult in general, and in software development it becomes even more complicated if the software process is changed. In this paper a number of alternative interview-based effort estimation methods is presented. The main focus of the paper is to present an experiment in which software engineers were asked to use different methods to estimate the actual effort it would take to perform a number of tasks. The result from the subjective data is compared with the actual outcome from performing the tasks. © 1997 Elsevier Science B.V.

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1. Introduction

A major problem when introducing new technologies is that experience from former projects cannot be used to estimate the effort required to perform tasks similar to previously performed tasks. Thus, methods for estimating and predicting the impact of a change are needed. An impact analysis method has been proposed for process change proposals in software development processes [1], and the objective here is to perform an evaluation of one of the approaches advocated within the impact analysis method.

A particular challenge, of course, is to try to foresee the effect of a change when no objective data are available. In these cases, we have to resort to experts and their judgements. Thus, through interviews and filling out templates, it is possible to get the opinions of experts in specific areas. For example, the effect of a change may be in several subprocesses within the development process, hence it is important to collect the subjective estimates from experts from different areas in order to predict the overall effect of the change.

The objective here is to present an experiment [2,3], or actually a first limited experiment (denoted pre-study experiment), by which we would like to evaluate the opportunity and accuracy of predicting the effort for a specific task in advance. The experiment is focused on effort estimation without focusing on process change. In particular, we would like to investigate different methods for capturing the actual variations observed. It is essential not only to rely on a mean value prediction by the experts, but to obtain a comprehensive picture including the variance around the predicted mean value.

In the impact analysis method, based on a planned process change, a number of experts are asked to estimate the mean effort required and the uncertainty. The latter is explained to the experts through a distribution or by letting them estimate the expected lowest and highest values. The objective in the experiment is to evaluate how the experts should be asked to do the estimations in order to reflect the actual outcome. Thus, in the experiment the experts are asked both to perform the estimation and to perform the task, then based on this information the objective is to determine which method or methods are best used to estimate the uncertainty.

The experiment is conducted by letting the experts first do the estimations and then perform the task, in this case conducting a number of the exercises in the Personal Software Process (PSP) [4]. Instead of doing an extensive experiment directly, it was decided to perform a pre-study experiment in order to gain further understanding of the problem at hand. Furthermore, the objective is to evaluate whether the experiment could be limited to using fewer potential methods to gather the information from the experts, and to do the analysis of the collected data.

A simple process for predicting the effort is as follows:

- Present the prerequisites, in terms of background and estimation method.
- The experts provide parameters requested by the method of estimation used.
- Estimate the mean and the standard deviation of the

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required effort based on the subjective data. The mean value is used for prediction and the standard deviation of the data is used to describe the uncertainty.

The experiment presented here focuses on evaluating a number of different methods to be used by the experts to estimate the parameters, and on evaluating the methods for turning the expert opinions into a prediction of the actual outcome in terms of both mean value and variation. The experiment should be of interest for anyone estimating effort based on subjective data. Furthermore, the method presented assumes that different types of estimates can be combined into one estimate. This type of experiment can be conducted to evaluate other combinations of estimation techniques, not only in software development but also in other areas.

The outline of the paper is as follows. In Section 2, the background in terms of the impact analysis method is briefly presented. Section 3 describes the experimental plan, and Section 4 presents the design of the pre-study experiment. The analysis of the data from the pre-study experiment is presented in Section 5 and, finally, some conclusions are presented in Section 6.

2. Background: impact analysis

One important part of software management is the introduction of new software process technology, either in the form of new methods for developing software, or in the form of new tools to provide support in development. New technology is introduced in order to meet improvement goals, but it is almost never obvious in advance that new technology actually will meet the goals. Therefore, methods for predicting the actual impact of introducing process changes in order to reach process improvements are needed, and one approach to this is the impact analysis method, presented in [1].

The impact analysis method does not rely on any real development, i.e. any usage of the process model changed according to the change proposal under investigation. This allows for an early investigation with lower effort required than if actual development was necessary. Instead, other means of estimating the effects are necessary. This problem is solved by relying on subjective estimations of the impact on sub-processes from experts representing the sub-processes.

The impact analysis method is performed in three steps:

1. Data collection: The impact on sub-processes is predicted, by interviewing, for example, design or configuration management experts. This step corresponds to the process outlined in the previous section.
2. Prediction: The overall impact is predicted from the sub-process predictions. This is done using, for example, models for reliability, required effort, and development time.
3. Presentation: The result of the prediction step is presented first to the experts and then to management as a basis for deciding how further to handle the proposed process change.

To predict the effects of a change with respect to required effort, the required effort must be estimated for a typical project where the change is not introduced and for a typical project where the change is introduced. This means that the required effort must be estimated for a number of sub-processes where we do not have any experience.

The objective of the data collection phase of the impact analysis method is to estimate the mean and the variance of the aspect of interest (e.g. the required effort). The process, presented above, for estimating the effort can also be used for a number of other attributes, for example, the lead time of a sub-process.

In this experiment we limit our study to effort estimation in order to understand effort estimation and, in particular, the uncertainty of the estimates. The long term objective is to include the results and the insights from the experiment into the impact analysis method. The objective is not to evaluate the process changes in the PSP. The focus is solely on effort estimation ability.

3. Experimental plan

3.1. Introduction

The overall experimental plan directs that the experiment should be performed in two steps. First a pre-study is performed with a limited number of experts (five persons). Second, a more extensive experiment is planned, and should be performed based on the results from the pre-study.

The experimental plan is only outlined here, and the focus is primarily on the design and performance of the pre-study experiment.

3.2. Objective of the experiments

The general objective of the experiment is to evaluate the opportunities to predict the required effort and estimate the certainty of the prediction, by interviewing software engineers or other experts (e.g. process owners) about their opinions of the effects. More specifically, the objective of the presented experiment is to answer the following questions:

- What are the best prerequisites to present to the experts? That is, what aspects should the experts be asked to estimate? This can for example be the most likely value, the lowest and highest possible value or an interval containing the real value.
- What is the best way to analyse the results from the individual estimates? That is, how can the result of the interviews be analysed and what are the best assumptions to make about the parameters of the distribution for

the actual amount of effort? How can the mean and standard deviation be estimated from the estimators' different individual estimates?

Some different prerequisites have been formulated and some alternatives for the way of analysing the result of the interviews have been formulated. The objective of the pre-study experiment is to evaluate whether any of the formulated alternatives are significantly better than the others, or if any alternatives are significantly worse than the others. In the more extensive experiment, new alternatives will be formulated if the pre-study experiment indicates that new alternatives are needed. If some alternatives are significantly worse than the other alternatives, these alternatives will not be considered in the more extensive experiment.

3.3. Requirements for the experiments

As the objective of the experiment is to evaluate methods for estimating the mean and the standard deviation of a required effort prior to development, this requires that the estimated mean and standard deviation can be compared with the mean and standard deviation based on quantitative experience (the actual outcome). In the experiment, this requires that the same task be performed independently by a number of different software engineers, and that the spent effort be measured every time. This is fulfilled through the assignments in the PSP [4], see below.

The mean and standard deviation based on quantitative experience are compared with the mean and standard deviation estimated for each of the different alternative methods. As only one estimate from each alternative is not enough, it is required that the estimations and independent developments be performed for a number of different tasks.

To summarize, if the experiment is to be performed as outlined above, it is required that

- a number of different tasks are carried out.

Furthermore, for every task it is required that:

- the mean and standard deviation are estimated as described by every alternative, and
- the development is carried out independently by a number of software engineers. The required effort for every task is measured and the mean and standard deviation are calculated based on the measurements.

3.4. General design of the experiments

The experiments are performed in conjunction with performing the assignments of the PSP course [4]. The PSP course involves developing ten different programs, and each participant develops the programs independently of each other. This corresponds well with the requirements above (i.e., a number of tasks should be performed and each task should be performed independently by a number of different software engineers).

The experiments are performed with assignments 1A–10A of the PSP course. These assignments include programs for list handling, counting the number of lines of code using a coding standard, and a number of programs for different types of statistical analysis. For further information concerning the actual programs see [4].

All development is done by following a defined process that is the same for every software engineer. The process is enhanced during the assignments, from a basic process in the first assignment to a more advanced process in the last assignment. The assignments each requires about 100–500 min to perform. Assignment 10 requires more time than the others, while the other assignments each require about the same time.

The experiments are performed as an addition to the material in the PSP course. In addition to predicting the required effort according to the prediction procedures proposed by [4], the required effort is predicted according to the different alternatives formulated for the experiments.

4. Pre-study experimental design

4.1. Introduction

The pre-study has been performed as an addition to carrying out the PSP course at the Department of Communication Systems at Lund University at postgraduate level. The predictions according to the experiment have, however, been done after the course has finished. All of these predictions were made on one occasion after the development of the last assignment. This is further elaborated below.

4.1.1. Background

The PSP course was followed by five people (in this paper referred to as experts or software engineers) during the spring of 1996. In the pre-study experiment, the experts had already done the assignments and measured the effort it took to do the assignments. In every assignment, the experts also carried out effort estimation according to the methods described in the PSP. Thus, the different methods for presenting the problem to the experts and actually doing the estimates of the variations have been done in retrospect.

As the experiment was performed in September 1996, and the PSP course was held in the spring of 1996, at the time of the experiment at least three months had passed since the last assignments were done. This, together with the fact that each carried out 10 different assignments, means that the experts could not remember details of the effort actually required in the assignments.

Before the experts are asked to estimate the required effort in the assignments, the estimates from the PSP course are put together on individual forms for each expert. This process is further described below.

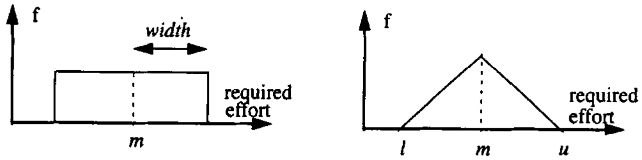


Fig. 1. The probability density function of the rectangular distribution and the triangular distribution.

The pre-study experiment was carried out at the Department of Communication Systems, Lund University and the more extensive experiment will be carried out at the Department of Computer and Information Science, Linköping University, in the spring of 1997. The expected number of participants in the experiment in Linköping is 20–30 people.

4.1.2. Presentation of prerequisites for prediction

The experts are asked to predict the required effort for each assignment three times, based on three different prerequisites. The prerequisites prescribe how the experts should envisage the actual distribution of the required effort. The three different prerequisites are:

- The required effort is distributed according to a rectangular distribution (see Fig. 1), and the mean value, m, has already been estimated (the prediction from the PSP course). In this experiment, the width should be estimated for each assignment. The estimates of mean and width can then be used to derive estimates of the lowest possible value as $l = m -$ width, and the highest possible value as $u = m +$ width.
- The required effort is distributed according to a triangular distribution (see Fig. 1), and the most likely value, m, has already been estimated (the prediction from the PSP course). In this experiment, l and u should be estimated for each assignment.
- No specific distribution must be considered. A most likely value, m, has already been estimated (the prediction from the PSP course), and in the experiment a highest possible value, u, and a lowest possible value, l, should be estimated.

4.1.3. Estimation of parameters

The experts are asked to estimate parameters for the three prerequisites. This is done at a 1 h meeting, where the prerequisites are first presented, and forms for estimation are then handed out. For every assignment, the experts make their estimates by filling in the following values on the form:

- The width of the rectangular distribution.
- l and u for the triangular distribution.
- l and u for the case when no specific distribution must be considered.

As mentioned in Section 4.1.2, some of the parameters of the distributions have already been estimated in the PSP course. This explains why the mean value of the rectangular distribution and the most expected value in the other two cases are not estimated. These values are already filled in on the forms when they are handed out to the experts.

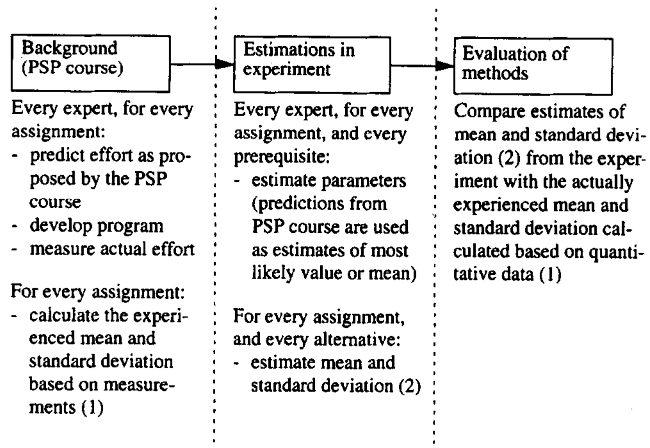


Fig. 2. Summary of estimations in pre-study experiment.

In order to clarify when different estimations are done, and how the estimations from the PSP course are used in the experiment, the pre-study experiment is outlined with respect to the estimations in Fig. 2.

4.1.4. Analysis of data

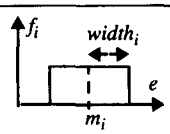
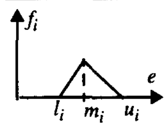
The individual estimates are synthesized to form a new distribution that can be used to estimate the mean and the standard deviation (or the variance, which is the square of the standard deviation) of the required effort. There are a number of ways to synthesize the estimates. Three alternative ways have been formulated for the case in which experts estimate the parameters of the rectangular distribution:

- Alternative 1: Estimate the mean and the variance based on the average distribution

  $$f = \frac{1}{n}\sum_{i=1}^{n} f_i$$

  where f_i are the different rectangular distributions individually estimated by the experts and n is the number of experts. In Appendix A the method of estimating the mean and the variance is given.
- Alternative 2: Estimate the mean and the variance based on a rectangular distribution with $l = \min l_i$ for all i, and $u = \max u_i$ for all i, where l_i and u_i are the individual estimates of the lowest possible value and the highest possible value. Appendix A gives the method for estimating the mean and the variance.
- Alternative 3: Estimate the mean and the variance based on a rectangular distribution with $l = \bar{l}$ (i.e., the mean of the experts' individual estimates of the lowest possible value), and $u = \bar{u}$ (i.e., the mean of the experts' individual estimates of the highest possible value). Appendix A specifies how to estimate the mean and the variance.

Table 1
Summary of distributions presented to experts and distribution alternatives used for estimation of the mean and the standard distribution

Basic distribution	Rectangular	Triangular	Standard PERT technique based on Beta distribution
Distribution as presented to the experts			No distribution presented to the experts
Synthesized distributions used for estimation of mean and standard deviation	alt 1: $f = \frac{1}{n}\sum_{i=1}^{n} f_i$	alt 4: $f = \frac{1}{n}\sum_{i=1}^{n} f_i$	alt 7: Beta distribution
	alt 2: Rectangular distribution with $l = \min l_i$ and $u = \max u_i$	alt 5: Triangular distribution with $l = \min l_i$, $m = \bar{m}$ and $u = \max u_i$	
	alt 3: Rectangular distribution with $l = \bar{l}$ and $u = \bar{u}$	alt 6: Triangular distribution with $l = \bar{l}$, $m = \bar{m}$ and $u = \bar{u}$	

Three alternative ways to synthesize a distribution (with a notation similar to that for the rectangular distribution) have been formulated for the case in which the experts estimate parameters of the triangular distribution:

- Alternative 4: Estimate the mean and the variance based on the average distribution

  $$f = \frac{1}{n}\sum_{i=1}^{n} f_i$$

  Appendix A describes how to estimate the mean and the variance.
- Alternative 5: Estimate the mean and the variance based on a triangular distribution with $l = \min l_i$ for all i, $m = \bar{m}$ and $u = \max u_i$ for all i. Appendix A specifies how to estimate the mean and the variance.
- Alternative 6: Estimate the mean and the variance based on a triangular distribution with $l = \bar{l}$, $m = \bar{m}$ and $u = \bar{u}$. Appendix A gives the method of estimating the mean and the variance.

If no distribution at all is presented to the experts as a prerequisite for the estimation, the mean and the variance can be estimated with standard PERT procedures as described in [5] and Appendix A (Alternative 7).

The distributions presented to the experts as prerequisites and the different synthesized distributions are summarized in Table 1.

4.2. Threats to experiment

It is always difficult to draw valid conclusions from experiments. It can be difficult to know whether the result is general enough (e.g., is the result valid for the data collection phase of the impact analysis method?). It can also be difficult to know whether the conclusions drawn from the experiment are correct (e.g., are our conclusions statistically significant?).

The following threats to the validity of the pre-study have been identified:

- The estimations are made with respect to small assignments that are performed by only one person independently of other assignments. It would probably be harder to estimate the required effort in a development task if this task depended on other tasks to be finished, and if the amount of work required in the task was dependent on the quality of the result of previous tasks.
- Values, in the PSP course originally estimated as the mean of the required effort, are used as estimates of the most likely value of required effort and not the mean value of required effort. When the experts should estimate, they have already estimated the mean value once while doing the exercises in the PSP course. This is no problem when the estimations should be done based on the rectangular distribution, since then it is natural to estimate first the mean and then the width. When the estimation should be done based on the triangular distribution, however, there are some problems. It is not possible to let the experts estimate the mean (from the PSP assignments), a most likely value (the top of the triangle) and also an upper and a lower value, since this would require that the experts would have to estimate the three new values so that they result in the right mean value. Instead, it has been decided that the value predicted in the PSP assignments corresponds to the most likely value. This will mostly influence the predictions of mean values, and we do not consider it a major problem in the estimation of the standard deviations. If the triangular distribution is estimated to be symmetrical, then the mean will be the same as the most likely value.
- The required effort is estimated after the actual development is performed, and therefore the experts have experience from doing the assignments. There is a chance that the experts remember the actual effort that was required, and therefore there is a chance that the

Table 2
Mean and standard deviation based on the seven alternatives ("alt 1"–"alt 7") and measurements made during the PSP course ("PSP data")

Prog		alt 1	alt 2	alt 3	alt 4	alt 5	alt 6	alt 7	PSP data
1	e	246.0	297.5	246.0	229.3	222.0	229.3	234.0	182.0
	s	64.70	88.04	45.61	49.86	65.87	38.42	28.67	37.60
2	e	174.0	187.5	174.0	188.7	224.7	188.7	178.3	172.8
	s	59.95	93.82	32.33	69.11	83.6	29.04	21.67	49.08
3	e	195.8	268.5	195.8	209.9	245.3	209.9	204.4	286.6
	s	104.8	119.2	38.11	93.71	75.54	22.21	20.17	75.44
4	e	141.4	171.0	141.4	144.8	163.8	144.8	143.3	162.0
	s	51.11	74.48	30.60	49.46	51.64	21.47	17.67	46.19
5	e	174.4	225.0	179.4	187.8	219.8	187.8	185.0	159.2
	s	72.57	104.5	39.26	67.74	78.87	22.65	20.9	41.72
6	e	220.8	202.0	220.8	239.9	238.6	239.9	230.5	329.8
	s	75.85	117.8	50.81	58.19	62.58	35.96	30.67	96.37
7	e	169.0	171.0	169.0	178.1	179.7	178.1	173.5	169.8
	s	60.84	71.59	28.64	57.31	55.24	21.63	17.80	56.69
8	e	176.0	179.5	176.0	174.7	178.7	174.7	175.4	173.0
	s	67.54	70.53	25.98	62.56	49.00	16.34	13.70	66.26
9	e	277.6	322.0	277.6	278.9	289.2	278.9	277.6	309.8
	s	120.9	129.3	41.57	107.2	83.79	29.60	25.50	122.3
10	e	394.4	384.5	394.4	393.1	398.1	393.1	393.4	425.4
	s	147.8	153.9	45.61	145.4	102.1	34.09	29.50	207.9

experts avoid estimating intervals that do not contain the actual value. Since almost half a year has passed since the first estimations, and this factor would influence all of the methods, it is therefore considered not to be a major threat to the experiment.

- All estimations are done on one occasion. This means that the experts may compare the different alternatives with each other. Hence they are led to considerations that they would not have made if they were to estimate in only a single way. This risk is not considered crucial.

5. Pre-study data analysis

The data provided by the experts have been analysed according to the seven alternatives proposed in Section 4.1.2 (see also Table 1). The result from the analysis is presented in Table 2. The values in the columns denoted "alt 1" to "alt 7" are estimates of the mean and the standard deviation based on the data provided by the five experts in the experiment. The values in the column denoted "PSP data" are the values actually experienced, calculated based on the data that were measured by the same five experts according to the PSP course. The mean is denoted e and the standard deviation is denoted s.

It can be seen that the estimated values of the mean do not differ as much as the estimated values of the standard deviation for the seven alternatives. The reason is probably that the experts have used the same prediction from the PSP course as an estimate of the mean for the rectangular distribution as for the most likely value of the triangular distribution and Alternative 7. This means that the estimate of the mean will not differ very much between the different alternatives.

The distributions are estimated to have nearly the same mean value, even if the form of the distributions is estimated to be different for the separate alternatives.

In Table 3, a number of correlations (see for example [6]) are shown. In the second column, the correlation between the mean estimated as proposed by the seven alternatives and the experienced mean calculated based on measurements in the PSP course is shown. The correlation between the standard deviation estimated as proposed by the seven alternatives and the experienced standard deviation calculated based on measurements in the PSP course is shown in column 3.

It can be seen that the correlations with respect to mean values are reasonably high, and that the differences between the individual values are relatively small. The small difference is due to the difference of the estimates according to the seven alternatives being small.

Concerning the estimation of the standard deviation, it

Table 3
Correlation between estimated mean and standard deviation and experienced mean and standard deviation

Alternative	corr(estimated mean, experienced mean)	corr(estimated standard deviation, experienced standard deviation)
1	0.845	0.906
2	0.738	0.828
3	0.843	0.457
4	0.893	0.901
5	0.885	0.655
6	0.893	0.366
7	0.876	0.516

can be seen that there, too, for most alternatives the correlations are large. This is partly because the standard deviation is larger for large assignments than for small assignments, and people also anticipate wider intervals for large assignments than for small assignments. Some of the alternatives provide, however, for better estimates of the variations, in terms of standard deviation, than the other alternatives. Alternatives 1, 2, 4, and 5 provide a good correlation between the standard deviation estimated by experts and the experienced standard deviation.

6. Conclusions

A number of different approaches of how to estimate the required effort and the certainty in terms of standard deviation have been investigated in the pre-study experiment. It has been observed that the average distribution (Alternatives 1 and 4) seems to be a good means of deriving a measure of uncertainty (the standard deviation). Alternatives 2 and 5 may also be worth investigating more carefully in the more extensive experiment.

The pre-study experiment does not indicate that new alternatives have to be formulated for the more extensive experiment. There is, however, a need to investigate more carefully which of the alternatives provides the best estimates. This can be done if the estimations by the experts are done according to the rectangular distribution and the triangular distribution, and if the estimations are done in the planning phase of the assignments when the PSP course is performed.

Future work includes performing the more extensive experiment based on the experiences and results from the pre-study experiment. As this will involve more people and the estimations according to the experiment will be done in the planning phase of the assignments, it will provide for a more thorough evaluation of the different alternatives.

The result of the experiment presented here indicates that the data collection procedure proposed by the impact analysis method [1] can be used to estimate effort, and hence its suitability to predict the impact of a process change proposal has to be further investigated. In the pre-study experiment, and in the more extensive experiment, the required effort for a process is estimated by experts directly without dividing the process into sub-processes. There is a need to perform additional experiments which involve larger software development processes, and where the estimations are done for sub-processes of the larger processes. This type of experiment is preferably conducted in an industrial environment.

Appendix A Analysis of data according to different alternatives

Appendix A.1 Introduction

In this appendix it is described, for every distribution presented to the experts as prerequisites (rectangular distribution, triangular distribution, and no distribution at all), how to estimate the mean and the variance. This is done for a number of examples of synthesized distributions. For every synthesized distribution, formulae for estimation of the mean and the variance are given.

Appendix A.2 Rectangular distribution

APPENDIX A.2.1 Alternative 1

Synthesized distribution: the average distribution

$$f = \frac{1}{n}\sum_{i=1}^{n} f_i$$

Mean and variance:

$$e = \frac{1}{2}(\bar{u} + \bar{l})$$

$$\sigma^2 = \frac{1}{3}\left(\overline{u^2} + \overline{l^2} + \overline{ul}\right) - e^2$$

APPENDIX A.2.2 Alternative 2

Synthesized distribution: rectangular distribution with $l = \min l_i$ and $u = \max u_i$.

Mean and variance:

$$e = \frac{1}{2}(l + u)$$

$$\sigma^2 = \frac{1}{3}\left(u^2 + l^2 + ul\right) - e^2$$

APPENDIX A.2.3 Alternative 3

Synthesized distribution: rectangular distribution with $l = \bar{l}$ and $u = \bar{u}$.

Mean and variance:

$$e = \frac{1}{2}(l + u)$$

$$\sigma^2 = \frac{1}{3}\left(u^2 + l^2 + ul\right) - e^2$$

Appendix A.3 Triangular distribution

APPENDIX A.3.1 Alternative 4

Synthesized distribution: the average distribution

$$f = \frac{1}{n}\sum_{i=1}^{n} f_i$$

Mean and variance:

$$e = \frac{1}{3}\left(\bar{l} + \bar{m} + \bar{u}\right)$$

$$\sigma^2 = \frac{1}{6}\left(\overline{l^2} + \overline{m^2} + \overline{u^2} + \overline{lm} + \overline{mu} + \overline{lu}\right) - e^2$$

APPENDIX A.3.2 Alternative 5

Synthesized distribution: triangular distribution with $l = \min l_i$, $m = \bar{m}$ and $u = \max u_i$.

Mean and variance:

$$e = \frac{1}{3}(l + m + u)$$

$$\sigma^2 = \frac{1}{6}\left(l^2 + m^2 + u^2 + lm + mu + lu\right) - e^2$$

APPENDIX A.3.3 Alternative 6

Synthesized distribution: triangular distribution with $l = \bar{l}$, $m = \bar{m}$ and $u = \bar{u}$.

Mean and variance:

$$e = \frac{1}{3}(l + m + u)$$

$$\sigma^2 = \frac{1}{6}\left(l^2 + m^2 + u^2 + lm + mu + lu\right) - e^2$$

Appendix A.4 No distribution presented

APPENDIX A.4.1 Alternative 7

If no distribution at all is presented to the experts as prerequisite for the estimation, the mean and the standard deviation can be estimated with standard PERT procedures as described in [5]. The mean and the variance can be estimated as

$$e = \frac{\bar{l} + 4\bar{m} + \bar{u}}{6}$$

$$\sigma^2 = \left(\frac{\bar{u} - \bar{l}}{6}\right)^2$$

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