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A Preliminary Risk-based Software Bidding Model

Barbara Kitchenham, Lesley Pickard, Stephen Linkman and Peter Jones

Email: barbara:cs.keele.ac.uk

Software Engineering Group
Department of Computer Science
Keele University
Keele, Staffs, ST5 5BG
England

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Abstract

This document outlines a preliminary risk-based software bidding model. It is based on the requirements for a bidding model identified by a review of bidding practices in software and other industries. The model is presented as a generic contributing-factor model that can be specialized by determining the distribution of input variables. The modelling method is explained by reference to a terrorist risk model.

The software bidding model is presented at two levels of granularity an overview and a more detailed model. We discuss the problems of validating the model and discuss the extent to which the model meets its requirements.

CONTENTS

1 Introduction

Pickard et al. (2000) reviewed the models used to assist bidding and portfolio management in other industries. Their results, together with the specific nature of software, indicate that a bidding model for custom-made software products should address the following issues:

- Assistance with the bid/no-bid decision as well as the pricing decision. This may require two separate models, or one model that can be used with preliminary data for bid/no-bid decisions and with more detailed data for pricing decisions.
- Consideration of the impact of over-booking strategies on schedule and delivery date. In practice, this involves assuming that potential projects put a reserve on available staff that is proportional to their probability of being accepted (Easton & Moodie, 1999).
- Consideration of both cost and timescale on bidding and pricing decisions. This implies considering the impact of delivery dates and costs on the probability of a bid being successful (Easton & Moodie, 1999).
- Consideration of the impact of competition and other factors on bidding and pricing decisions. This requires eliciting information from practicing managers about the factors that affect bidding and pricing decisions (Dawood, 1996).
- Consideration of the impact of Category 1 risk, i.e. uncertainty in cost (effort) estimates. Existing methods for defining cost estimation uncertainty (Fairley, 1994) and (Briand et al., 1998) are suitable for determining Category 1 risk, as long as both input error and model error are included in the assessment of estimate uncertainty.
- Consideration of the impact of Category 2 risk, i.e. the amount of contingency required to allow for unplanned tasks and delays. The approach suggested by Kitchenham and Linkman (1997) and Kansala (1997) which is based on assessing the impact of invalid assumptions, is a suitable technique for Category 2 risks.
- Consideration of the impact of Category 3 risk, i.e. the probability that the bid will be rejected and/or the probability that the project if started will fail completely. Dawood suggests that probabilities of this type can be based partially on past history (particularly the probability that a bid will fail). However, any historical data would need to be evaluated by experts in the specific context.
- Consideration of the impact of the project portfolio on the bidding process for an individual project. Some aspects of the portfolio would already have been considered when delivery dates were defined (i.e. the impact of actual and potential projects on availability). However, other portfolio management concerns would also need to be addressed. The experiences of the financial, insurance and pharmaceutical industries suggest that this would include the need to consider the extent to which the risks associated with the particular project affects the overall portfolio risk and may require the use of portfolio optimisation techniques.

The goal of such a model is not predictive in the sense that it does not produce a single output variable; it is descriptive. It is intended to allow users to investigate the risk implications of their estimates, assumptions, organisational constraints and strategies. This can be contrasted with a cost estimation model that attempts to predict the value of an unknown variable (e.g. staff effort) from other variables whose values are assumed to be known.

In this document, we present the first version of a model intended to address these requirements. We have based our modelling approach on simplified influence models called *contributing-factor diagrams* that can be animated using Monte Carlo simulation. This method was developed by Glen Koller (2000). Before presenting our model, we give an example of Koller's method (see section 2).

A risk-based software bidding model is rather complex, so we present the model at two levels of granularity. Section 3 describes our view of the software bidding process. Section 4 presents an overview of the bidding influence model, which is discussed in more detail in Section 5. In this report, we present only the contributing-factor diagram, a discussion of the elements in the diagram, and some elements of the mathematical model linking the elements of the model.

Section 6 discusses the problem of validating the model. Section 7 presents our conclusions and ideas for further research.

2. The Modelling Approach

The easiest way to describe Koller's modelling approach is by discussing an example. We use Koller's Terrorism Relative Risk Model (Koller, 2000) as an example of the model building process. Terrorism risk models are used by international companies to assess the relative risk of terrorist threats from doing business in foreign countries.

2.1 Defining the question

When building a risk model, the first stage is to define the question the model needs to address. Koller recommends determining the question by means of brainstorming sessions with the interested parties. He points out that such a session may identify several different questions. In the case of terrorism the questions might be:

1. What group of countries or regions in the world do we wish to avoid? This question would lead to a model that ranked all the different regions of the world in terms of their risk of terrorism. However, it might be too coarse grained - regions may be too large and diverse to be assessed as a whole.
2. Of the many countries we are considering, which countries represent the lowest overall threat from terrorist activities? This question would lead to a finer-grained model than question 1. The level of granularity is more compatible with investment decisions.
3. What types of terrorist activities should we invest in countering regardless of the countries being considered? This question would lead to a model classifying terrorist activities and assessing the effectiveness of various counter terrorism procedures.

Koller recommends further discussion, prioritization and voting as mean of deciding on the most appropriate question. The example was continued using question2.

2.2 Determining the output variable

Once the question has been decided, it is necessary to specify the nature of the output from the model. In the terrorism example, the alternatives might be:

- The total cost of terrorist activities to the company for the planned period of investment.
- A relative risk measure expressed on a scale of 1 to 10 where 1 is the lowest risk and 10 is the highest risk.

In this case, the relative risk measure was chosen. This was regarded as appropriate since most of the input variables could also use the 1-10 scale. Koller suggests working backwards from the questions to determine the appropriate unit for the output variables. Thus, in practice, it may be necessary to have some idea of the proposed model before finally deciding on an appropriate unit of measurement.

2.3 Building the Contributing-factor diagram

Brainstorming meetings are needed to determine the elements of the model. Often it is appropriate to perform a top-down decomposition of elements. In the terrorism example, three broad categories were identified:

1. Organisation: The effectiveness of the terrorist organisation.
2. Funding: The extent of funding and support available to the terrorist organisation.
3. Experience and Technology Prowess: how experienced the members of the terrorist organisation were and the extent to which they were able to exploit advanced technology.

Each of the categories was itself decomposed as shown in Figure 1 (figures are shown at the end of the report). The organisation category was split into three factors:

1. Level of Organisation: the extent to which the terrorist groups in a country are well organized. This was measured on a 1-10 scale.
2. Size of Organisation. This was measured on a 1-10 scale after transforming from a simple count of members e.g. 1 member was equated to a value 1, 2-5 members to a value of 2, etc., finishing with more than 200 members equated to a value of 10.
3. Logistical support from host government: The extent to which the host government supplies logistic support such as refusing to extradite known terrorists, allowing training camps and base camps within the host country. This was measured on a 1-10 scale.

The funding category was split into two factors:

1. Diversity of the funding base. Measured on a 1-10 scale.
2. Level of funding: Measured on a 1-10 scale.

The experience/ technology category was split into three factors:

1. Level of Experience of Members: the extent of experience and political acumen of the terrorist organisation, measured on a 1-10 scale.
2. Effectiveness of Execution: the extent to which the terrorist organisation is effective in their terrorist activities, measured on a 1-10 scale.

3. Level of Technological Prowess: the extent to which the terrorist organisation is able to exploit technology, measured on a 1-10 scale.

Full specification of the model requires:

- Defining each of the elements unambiguously.
- For input variables measured by arbitrary ranks, defining the measurement scale points for each variable, in particular the extreme values.

2.3 Category Weights

The terrorism risk model has three separate categories: organisation, funding and experience/technology. Weights can be used to emphasize or de-emphasize model components. For example, weights allow the risk model to cater for risks that can be controlled or mitigated and those that cannot.

In order to combine the output from each component into an overall assessment of risk the weights must:

- Take on values between 0 and 1
- Sum to 1.

2.4 Risk model equations

In order for the model to deliver output values, the elements of the model must be linked by one or more mathematical functions. The function must be specified by the interested parties.

For the risk model the agreed functions were:

org_risk=org_weight × (level_org+size_org+log_support)/3
fund_risk=fund_weight × (diverse_fund+level_fund)/2
exp_tech_risk=exp_tech_weight × (level_exp+effect_exec+tech_level)/3

total_risk=(org_risk+fund_risk+exp_tech_risk)

where

org_risk is the organisational risk
org_weight is the weight applied to the organisation category
level_org is the level of the terrorist organisation
size_org is the size of the terrorist organisation
log_support is the logistical support provided by the host government
fund_risk is the risk associated with funding
fund_weight is the weight applied to the funding category
diverse_fund is the diversity of funding
level_fund is the level of funding
exp_tech_risk is the risk associated with experience and technical prowess
exp_tech_weight is the weight applied to the experience/technical prowess category

level_exp is the level of experience
effect_exec is the effectiveness of execution
tech_level is the level of technical prowess
total_risk is the total calculated risk.

Since all the input variables are expressed as values on a 1-10 scale, total_risk is also expressed as a value on a 1-10 scale.

2.5 Generic and Specific Models and Monte Carlo Analysis

The risk model defined above is a generic model. It can be specialized by applying the model to the specific circumstances in a particular country.

To specialize the model, it is necessary to determine the input values in a particular situation. If you fix specific values for each input variable and the weights, you can calculate a single value output. However, this does not reflect the uncertainty that arises because the input values are *estimated*.

In order to model the uncertainty in the output value, it is necessary:
1. To model the distribution of the input values for each variable.
2. To determine the distribution of the output variable. This is done by calculating many values of the output variable (e.g. 500 or 1000) for different input variable values. Each input variable value is obtained by sampling the input variable distribution.

The process of repeatedly sampling the input distributions in order to generate the output distribution is called Monte Carlo analysis.

2.6 Defining the input variable distribution

Koller requires model users to specify input variable distributions in terms of the following types of distribution:
1. Symmetrical distributions. These are defined in terms of a maximum and minimum value.
2. Skewed distributions. These are defined in terms of a maximum, minimum and most likely value.
3. Spiked distribution. This is a distribution comprised of a single value - i.e. a variable that is not subject to any uncertainty.
4. Flat (uniform) distribution. This is a distribution where all values across the stated range are equally likely to occur. It is defined in terms of a maximum and minimum value.
5. Truncated distribution. This is a single tailed distribution where either the most likely value is the same as the minimum (left truncated) or the most likely values is the same as the maximum (right truncated).
6. Discrete distributions. This occur when a variable can only take one of a small set of different values. Each value must be specified together with a weight that determines the relative frequency of each value.

7. Bimodal distributions. These distributions contain two most likely values. They are a combination of two distributions. So a bimodal distribution is defined by specifying each of the contributing distributions.

In addition, to the distribution types, Koller also uses the concept of *peakedness* to specify in more detail the shape of distribution with most likely values. He uses a peakedness measure in the range 0-10, where 10 indicates that the values are concentrated near to the most likely value and 0 indicates that the values are more spread out and values towards the tails of the distribution still have a reasonable chance of being selected.

Table 1 Parameter values for terrorism model

Category/Parameter	*Distribution Type*	*Minimum*	*Most Likely*	*Maximum*	*Peakedness*
Organisation Category					
Level of Organisation	Skewed	4	8	9	10
Size of Organisation	Truncated	7	10		5
Logistical Support from Host Country	Skewed	3	5	7	2
Funding Category					
Diversity of funding base	Skewed	5	7	9	1
Level of funding	Skewed	5	7	9	1
Experience/ Technology Category					
Level of Experience of Members	Truncated	5	10		10
Effectiveness of Execution	Skewed	3.5	5	6.5	1
Level of Technical Prowess	Bimodal Skewed	2.5	3.5	5	3
	Bimodal Skewed	6	7.5	8	7
Category weights					
Organisation Category weight	Spiked		0.15		
Funding Category Weight	Spiked		0.15		
Experience/ Technology Weight	Spiked		0.7		

In the case, of the terrorist risk model, when it was applied to a specific example, the input parameters to the model were specified as shown in Table 1. The weights are values between 0 and 1 that sum to 1. The other variables are real values between 0 and 10.

The bimodal distribution for technical prowess arose because the terrorist group under consideration usually employed low-tech tactics: beating with bats, pipe bombs, threats and attacks with hand-guns. However, they sometimes hired high-tech help when deemed necessary.

Examples of the distributions are shown in Figures 2-4. They were generated by sampling repeatedly from the distributions defined in Table 1. The skewed distribution of the level of organisation is shown in Figure 2. The truncated distribution for the level of member experience is shown in Figure 3. The bimodal distribution for level of technical prowess is shown in Figure 4.

2.7 Model Output

The distribution of the output variable can also be represented as a frequency distribution but it is more normal to represent it as a cumulative probability as shown in Figure 5. The modal value of the distribution in Figure 5 is approximately 6.5.

Figure 5 is plotted as a Z-curve. This is the opposite way to a customary cumulative probability curve which is plotted as an S curve. Koller suggests that the Z-shaped curve is more useful for risk assessment. The larger probability is near the Y axis which makes it easier both to incorporate the chance of failure into the risk assessment and to calculate risk-weighted values (see section 2.8).

2.8 Comparing Risks

One use of a risk model is to compare risks associated with different business opportunities. In the case of the terrorism risk model, the terrorism risks from different countries can be assessed using the model. Since the same model can be used to assess the terrorism risk in different countries, a simple method of comparison, is to model the difference in risk values for two different countries. Thus, each iteration of the Monte Carlo analysis, for each model, also calculates the difference in total risk between the two countries. This difference can be plotted as a cumulative probability distribution to allow the model users to decide which country has the lesser risk of terrorist activities.

If simple differences are not an appropriate means of comparison, Koller recommend the use of two measures:

1. Net risk-weighted value.
2. Economic risk-weighted resource value.

Both values depend on defining a limit line. The limit line splits the cumulative probability curve into two parts the part corresponding to failure and the part corresponding success, i.e. the limit line is the break-even point.

The net risk-weighted value is used when the output from the model is the cumulative distribution of the financial value of a business opportunity (or threat). In this case the limit line is usually placed at zero on the x-axis. The Net risk weighted value is then calculated as:

Net risk weighted value= (Area under cumulative probability curve for x>0)
- (Area above curve for x<0).

The economic risk-weighted resource value is appropriate when the output from the model is not expressed in monetary terms e.g. it is expressed in units such as gallons or barrels of liquid, or other units that do not take on negative values. In this case the limit line corresponds to the lowest acceptable limit of production.

Calculation of the economic risk weighted resource value is rather complicated and somewhat counter-intuitive:

Economic risk weighted resource value = (Area under probability curve for x>limit)
+ (Area of "box "corresponding to x<limit and x>=0 and
y=intercept of limit line and probability curve)

The area calculated by the economic risk-weighted resource value (ERWR) is illustrated in Figure 6. If the limit line is set at 450, the ERWR corresponds to the shaded area in the figure.

3 The Software Bidding process and Its problems

3.1 The Software Bidding Process

The model we develop in this document is based on contract-based software production. Contract-based production applies to custom-made software applications purchased from independent suppliers. The award of a contract is usually based on evaluating a set of bids obtained from a number of different potential suppliers. Our model takes the viewpoint of a supplier organization.

Within a software development organisation, the software bidding process involves the following steps:

1. The organisation receives an Invitation to Tender (ITT) from a potential client.
2. The bid recipient (usually in the marketing or sales department) makes an initial decision whether or not to bid in response to the ITT. This may involve consultation with the development groups and senior management.
3. If it is decided to construct a bid, a bid team is assembled. For small bids this may be a single person but for large bids this may involve representatives from senior management, the marketing/sales division, development groups (software and hardware), and manufacturing (if hardware development is required).
4. The bid team construct a bid
5. Senior management review the bid and make the final bid/no bid decision
6. If the decision is to bid, the bid is submitted to the client

A bid includes information such as:

- The approach the company will take to meeting the customer's requirements.
- A statement of compliance specifying how each customer requirement will be met.
- The date when the software product will be delivered.
- The price the company will charge for the job.

Once a bid is accepted it becomes the basis for a formal contract.

Issues that arise in the bidding process are:

- Deciding what factors should influence the bid/no-bid decision before a large amount of effort has been expended on bid preparation.
- Collating information from many different organisational groups in an efficient manner.
- Deciding a competitive price and delivery date.
- Identifying the risks associated with the bid.
- Deciding what factors should influence the bid/no-bid decision after the bid has been prepared.
- Evaluating the probability that the bid will be successful.
- Evaluating the probability that the project will be successful, if the bid is successful

Our bidding model is intended to throw some light on all these issues.

In our experience, the software industry often claims to have estimating problems. However, cost estimation addresses only point 3, and even point 3 is only partially addressed. In practice, cost estimation research is not widely used in industry because little research has considered the context within which the results of cost estimation are used. Furthermore in the context of a bidding situation, cost estimation models are considered unhelpful because they are extremely inaccurate and managers do not know how to deal with the uncertainty in the estimates.

The goal of our research is to address the wider issue of the software bidding process. We hope that taking the wider view will enable industry to gain a better understanding of how to use existing research constructively.

In the next few paragraphs we discuss some important facets of the bidding process.

3.2 Bidding Decisions

There are two major decisions in the bidding process:

- Deciding whether or not to bid at all.
- If bidding is appropriate, deciding what price and time scales (or delivery date) should be included in the bid.

The basic pricing problem in software bidding is determining a price for the proposed work such that:

1. The price is not too high and the bid is rejected.
2. The price not too low and the bid is accepted but the project makes a loss.

There is also a problem of committing to a delivery date that cannot be achieved. However, since there are usually financial penalties for missing delivery dates, this problem can be regarded as a special case of point 2 above.

3.3 Pricing

We believe that the price that suppliers quote in bids should have three components:
1. Basic costs
2. Contingency
3. Profit

Basic costs are staff and material costs. In general the major costs in software intensive projects are staff costs although there may be additional costs associated with the purchase of special software (such as compilers and development tools) or special hardware. We believe the cost element of the price should be the basis of the project budget.

Contingency is the amount of the purchase price allocated to managing residual project risks. We take the viewpoint that contingency should be estimated as sum of the *expected loss* associated with managing all unfavourable events that are not explicitly costed for in the plan. The expected loss for a particular unfavourable event is the probability that the unfavourable event will occur multiplied by the cost of managing the event if it does.

For example, there is always a small chance that a company's office will burn down. In order to manage this event, there will be basic procedures such as taking periodic archives and storing them appropriately that will be included in the plan. However, if there actually were a fire there would be associated costs of hiring new computers and office space, and delays as back-up systems were installed. In some companies a proportion of the fire insurance costs would be included in the basic costs, but the manpower needed to get the back-up systems on-line would probably not be included since a fire is not certain to occur. Additional manpower costs and costs resulting from any delays would be included in the contingency element of the price.

In our view, contingency should be held separately from individual project budgets. It should be kept as a central resource and released to projects if specific unfavourable and unpredictable events occur. Thus, the administration of the contingency fund is a portfolio management function (see Section 3.5).

The profit element in the price is the element of the price needed to ensure that a company trades profitably. A company determines its profit margin by considering either a strategically determined profit level, or the specific nature of a particular bid such as the number and experience of likely competitors.

A company may decide to use a negative profit element in cases where it is considered of major strategic value to the company to win a specific bid. This is a perfectly valid senior management decision, however, it can cause a significant problem if the company is not prepared to accept the consequences of a low bid. A frequent response is for the project budget to be cut irrespective of the ability of the project manager to reduce costs.

3.4 Risks and Uncertainty in the Bidding Process

We define the term “risk” to be a future event that has a probability of occurring and which would incur a cost if it did occur. Following the definitions given by Pfleeger (2000), the probability of the event is called the *risk probability*; the cost incurred if it did occur is called the *risk impact*. Risk impact multiplied by the risk probability is called *risk exposure*. Risk exposure is the same thing as expected loss. In the United Kingdom, particularly in the safety community, the term hazard is often used instead of risk, and the term risk would be used instead of risk exposure

In the bidding process, the risks are bidding for infeasible projects, and pricing too high or pricing too low. In each case, the risk impact and risk probability are hard to quantify because of the uncertainties inherent in the feasibility evaluation and pricing process. Uncertainty in the pricing process is caused by three factors:

1. Costs and delivery dates for software projects cannot be assessed accurately, furthermore the earlier in the lifecycle of a project the less accurate estimates are likely to be.
2. It is difficult to determine the probability of an unplanned event occurring during the project and its cost impact if did occur, so contingency cannot be assessed accurately.
3. The probability of a bid being successful for a specific price cannot be accurately assessed.

There are a variety of factors that would lead to estimates of cost and delivery date being more or less accurate. Most of these factors also impact any assessment of project feasibility. Clearly the less accurate the cost and duration estimates, the greater the probability of a poor pricing decision. The main factor that reduces the accuracy of cost and duration estimates is the novelty of the application. There are several aspects of “novelty”:

- If the application itself is novel - i.e. does things that no other applications have done before.
- If the application area is new to the bidding company, or to the proposed software team.
- If the customer or senior managers mandate the use of specific methods or tools that company personnel have no experience with.
- If the application is not well understood by the customer.

Thus, application novelty is often considered to constitute a significant risk to a project.

Other conditions that are well known to result in significant project problems include:

- The imposition of “hard” deadlines that are (or may be) inconsistent with the amount of work required.
- Reliance on other novel systems such as new hardware or new operating systems that are not within the control of the software production company.

However, it is not possible to predict costs with absolute accuracy, even of well-understood projects with realistic time scales and no external dependencies. Factors such as productivity differences among software engineers and variations in task difficulty mean that predictions always have an element of uncertainty.

3.5 The impact of current work on the bidding process

Although any specific bid relates to a specific potential project, we believe an important element of the bidding context is the set of projects currently being managed by the company. The project set includes planned projects (i.e. projects that have been agreed with clients) and potential projects (projects for which bids have been submitted but the outcome is not yet known). We refer to this set of projects as a company’s project ***portfolio***. We take the view that failure to consider the portfolio viewpoint can damage the bidding process and result in unexpected knock-on effects on other projects (Kitchenham and Linkman, 1997).

For example, without a portfolio viewpoint, the bidding process cannot investigate whether the residual risks associated with the current proposal are large enough to have a significant impact on the company’s overall risk exposure. The total risk exposure of a company is the sum of the risk exposure for each current and potential projects and is therefore a portfolio not a project measure. In addition, failure to consider the time scales and resource requirements of other current and potential projects can lead to a situation where there may be insufficient resources available to start new projects when they are planned. Resource shortages and ensuing delays may then propagate over the whole portfolio.

4 Outline Software Bidding Model

A high-level outline model is shown in Figure 7. Relationships between elements in this model are discussed in more detail in Section 5.

4.1 Questions the model should answer

The bidding model needs to address six main questions:

1. Should we bid at all?
2. What price should be quoted in the bid?
3. What delivery date should be quoted in the bid?
4. What is the probability of the bid being successful, given the quoted price and delivery date?
5. What are the main areas of risk associated with the bid?
6. If the bid is successful, will the project be profitable?

Answering these questions should assist bid managers to assess whether or not to bid for the project. The outputs from this model can be used as inputs to models that assess the value of the project to the portfolio of projects undertaken by the organisation. However, an implication of having several different questions is that we may require several different models unless the model provides appropriate intermediate outputs.

For this preliminary model we will concentrate on answering questions 2, 3 and 4. This means we expect the following outputs:

1. Price in monetary terms
2. Delivery date
3. Probability of successful bid

4.2 Price

Price is the central element of the outline model. Our basic assumption is that price can be represented as a simple additive equation:

$$\text{Price (£)} = \text{Estimated cost (£)} + \text{Profit(£)} + \text{Contingency(£)} \quad (1)$$

The three input elements are discussed in more detail below.

4.2.1 Estimated costs

Estimated costs include staff costs and hardware/software costs. These costs are derived from the outline project plan. We assume that these costs are represented as a distribution of estimated costs (see for example Briand et al. 1998). Once the organisation determines the risk level for a project, a cost value can be obtained by simulating the distribution and reading the appropriate value from the cumulative probability distribution. For example a risk level of 70% would indicate that the organisation was prepared to accept a 30% risk that the project would cost more than the cost value used to construct the price.

Software development staff or managers must determine the cost estimation distribution. Assuming a skewed distribution, the distribution can be specified in terms of a maximum value, a minimum value, a mean value and an assessment of the peakedness of the distribution (on a subjective 1 to 10 scale). Senior management must define risk level. It can be treated as a fixed value or a random variable from a distribution. If risk level is modelled as a random variable it can be specified using a symmetric distribution in terms of a maximum and minimum value and a peakedness value.

4.2.2 Profit

The profit element in the pricing equation is based on the return an organisation expects on its projects. We model profit as a percentage of the cost component. Price values may be adjusted according to:

- The importance of the project to the organisation in terms of its strategic business goals. If a project is important, an organisation may reduce its required profit level in order to increase the probability that the bid is successful.

- The impact of competitors in the bidding process. The presence of competitors may require that the profit level be reduced in order to increase the probability that the bid is successful.

The profit level variable may be modelled as fixed value, or a random variable obtained from a profit level distribution.

One way of modelling importance and competition is to construct a discrete scale for each factor and associate an adjustment level with each scale point. For example, suppose importance of the project to the organisation was assessed on a four point ordinal scale: critical, significant, nominal, unimportant. Then, for each point on the scale, we must define the adjustment that will be made to the profit level. This can be defined as a multiplicative or additive adjustment. The adjustment may be modelled as a fixed value or a random variable from a defined distribution.

For example, we might define additive adjustment factors associated with each of the scale points as: critical: –7%, significant: -3%, nominal: 0%, unimportant: +5%. Then if the normal profit level was set at 15% of costs, and the project was assessed as significant, the actual profit level used to calculate the price would be reduced 3% to give a profit level of 12%..

Given additive adjustment factors, the equation used to calculate profit is:

$$\text{Profit} = \text{Estimated Cost} \times (\text{Profit Level} + \text{Importance Adjustment} + \text{Competition Adjustment})/100 \quad (2)$$

where Profit Level, Competition Adjustment and Importance Adjustment are percentages and Profit and Estimated costs are monetary values.

For a particular project, we might not be sure of the strategic significance a project. In that case we can associate a probability with each point on the scale for example: critical 0.1, significant 0.4, nominal 0.4, unimportant 0.1. In a Monte Carlo simulation, for each iteration, we would obtain a random number from a flat (uniform) distribution and use that value to determine the importance value as follows:

- If the random variable is in the range <0.1, importance is critical and the adjustment factor is –7%.
- If the random variable is ≥0.1 and <0.5, importance is significant and the adjustment factor is –3%
- If the random variable is ≥0.5 and <0.9, importance is nominal and the adjustment factor is 0%
- If the random variable is in the range ≥0.9, importance is critical and the adjustment factor is +5%.

If the adjustment factor for each category was also modelled as a random variable from a defined distribution, the appropriate distribution would be sampled once the importance level had been decided. The adjustment for competition can be calculated in the same way.

4.2.3 Contingency

Contingency is the cost allocated to handling rare events, i.e. events that are not included in the project plan because they are unlikely to occur. Like cost estimates, contingency can be represented as a random variable from a distribution. Unlike costs, the contingency distribution is a conditional distribution. There is a non-zero probability (p) that the scenario corresponding to the contingency does not occur.

The contingency cost distribution itself can be modelled as a skewed distribution. There are various alternatives for determining the contingency element to be included in the price. The approach we take is based on Kitchenham and Linkman's suggestion that contingency should be regarded in the light of an insurance premium. We suggest selecting a random value from the contingency distribution (C) and multiplying C by p (the probability that the event relating to the contingency occurs). The resulting value Cp can be regarded as the insurance premium for the project that is charged to the customer. As pointed out by Kitchenham and Linkman, if the contingency actually occurred it would cost C not Cp to handle. They suggest that the contingency from all projects managed by a particular organization should be held centrally to provide a large enough pool of resources to cater for the proportion of contingencies that actually occur.

The initial contingency, Cp, can be adjusted according to the current status of the organisation's contingency fund. If the contingency fund is low, the contingency for the current project should be increased and vice versa. The adjustment can be calculated using a subjective ordinal-scale assessment of the status of the contingency fund. Note. An equivalent procedure is to adjust the probability of occurrence, p, up or down according to the status of the contingency fund.

4.3 Estimated Delivery Date

The later the delivery date quoted in the bid, the less likely it is that a proposal will be accepted by a client, so like the price the proposed delivery date impacts the probability that the bid is successful. The expected delivery date of a project depends on the amount of work to be done and the team size and the amount of work already being undertaken by the organisation.

In practice it is usual to estimate project duration and calculate the delivery date from a given start date. Duration can be modelled as a skewed distribution with parameters (minimum, maximum and peakedness) specified by the software production group. Again we would need to select a value from the duration distribution to include in the bid. In order to determine an appropriate value, senior managers would need to determine an acceptable risk level for duration.

If the duration distribution is originally based on the work required to complete the proposed project in the absence of an assessment of total organisation workload, the selected duration value can be increased to cater for overbooking. Assessment of total workload is based on many projects, so it requires a senior management viewpoint.

The assessment could be done using an ordinal scale measure of total workload in a similar way to the importance assessment. A more sophisticated staffing profile model would need to consider the staffing profile of the proposed project over the duration of the project compared with the organisation's total staffing profile based on existing projects with an allowance for other proposals. The latter model is beyond the scope of our current research project, so our preliminary model will use a simple adjustment model.

4.4. Probability of a successful bid

Assuming a bid meets the client's functional and performance requirements, the probability that it is successful is a function of the price and delivery date quoted in the bid. Representatives of the marketing or sales group must define a probability distribution for price and a probability distribution for delivery date from their knowledge of the client requirements. The distributions would identify the probability of success for a range of price values and a range of delivery date values. These are the "price to win" and "delivery date to win" (or equivalently, "duration to win") distributions.

The distribution must be specified *independently* of the price and delivery date estimates estimated by the software development group. The model allows the different groups involved in bid construction to present their view of bidding issues. The marketing/sales group will provide information about the price and delivery dates from the viewpoint of winning the contract. This needs to be compared with the software developer's evaluation of the costs and delivery date needed to complete the required product. Comparing the "price to win" distribution with the "price to produce" distribution, we can calculate the probability that the price to produce will be accepted by the client. This probability is equated to the probability that the bid will be successful relative to price. We can make a similar assessment of the probability that the delivery date will be accepted.

The overall probability of a successful bid given the price and delivery date needed to produce the required application can be calculated by multiplying the probability of the price being successful by the probability of the delivery date being successful (assuming the probabilities are independent).

4.5 Example

Using the fictitious data shown in Table 2, the model produces the price and delivery date distribution shown in Figures 8 and 9. We assume that these distributions are obtained using cost estimate and delivery date information provided by the software production group and represent the price and delivery date needed to produce the required application.

Table 2 Example data (In all cases peakedness is assumed to be average)

Category/ Parameter	Distribution type/ Category	Min	Most Likely	Max	Prob-ability	Adjustment

Cost						
Expected costs (£)	Skewed	90,000	100,000	150,000		
Risk level (probability)	Symmetric	0.6		0.8		
Profit						
Profit level(%)	Spike		15			
Competition	Extensive Nominal Low				0.1 0.8 0.1	-5(%) 0 +7
Importance	Critical Significant Nominal Unimportant					-7(%) -3 0 +5
Contingency						
Cost (£)	Skewed	30,000	50,000	100,000		
Probability of occurrence	Spiked		0.1			
Fund Status	Low Nominal Large Very Large				0.1 0.4 0.4 0.1	+0.05 (probability)[1] 0 -0.03 -0.05
Delivery date (assuming an August start)						
Duration (months)	Skewed	8	9	12		
Workload	Critical Significant Nominal No backlog				0.1 0.3 0.5 0.1	0.8 (probability) 0.6 0.5 0.3
Marketing						
Price to win (£)	Skewed	90,000	120,000	180,000		
Duration to win (months)	Skewed	7	8	11		

The figures are based on a simulation of 250[2] iterations. The distribution of delivery date and price preferred by the client are given in Tables 10 and 11. We assume that these distributions are constructed by the marketing department based on information obtained from the client. In Figure 12, we compare the delivery date distribution provided by the software development group with the delivery date distribution provided by the marketing department. This figure indicates that if we submit a bid using our most probable delivery date (i.e. the delivery date we have a 50% chance of meeting) which is the beginning of May, we only have a 30% chance of providing a delivery date

[1] In this implementation, we use the assessment of the contingency fund status to provide an adjustment og the probability of occurrence.

[2] Restrictions in the STATA program caused us to restrict our Mont Carlo simulation to 250 iterations for the pricing model.

acceptable to the client (we equate this value to the probability of winning the contract with respect to delivery date). We can assess the price in the same way and arrive at an overall probability of our bid being successful by multiplying together the probability of a successful delivery date and the probability of a successful price.

4.6 Alternative Models

4.6.1 Time constrained projects

Our model is suitable for budget-driven projects or projects for which budgets and delivery dates are equally important. We assume that the estimating process starts with a cost estimate and the cost estimate drives the time scale estimate. However, in many cases, delivery dates are more critical than the budgets. In such cases, effort should be assessed once duration (and hence delivery date) has been specified.

A further significant class of projects is completely time constrained. In such projects, the software producers offer a set of requirements that can be provided in a given time scale. This scenario is usually associated with relatively small projects, such as enhancements to existing products. Much of the estimate uncertainty is reduced since the duration is fixed by the customer and the software developer's estimate only what can be delivered in the given time frame. The software development organisation has flexibility because it is in a position to define the product to be produced and because it has control of the project team size. The major risk with this type of project is that the work offered by the supplier does not match the customer's requirements. This type of project is well suited to situations where customer requirements are fairly vague but software developers have considerable expertise in the applications area. In such a situation, the software suppliers themselves define the product requirements and the customers must judge whether the supplier's view of requirements is a close enough match to their view.

4.6.2 Profit driven models

In some cases there is little flexibility in the price. For example, the marketing department and senior managers may have decided on a price prior to undertaking a full costing exercise. In such cases, it is more useful to treat price as an input variable and reorganize the model to output the distribution of a profit variable calculated as:

$$\text{Profit} = \text{Price} - \text{Cost} - \text{Contingency} \quad (3)$$

A profit distribution can give a good indication of whether or not it is worth bidding for a project. A profit model can also be used after a pricing model has been used to fix a price and delivery date to give senior managers an assessment of the overall monetary risks associated with the project.

A profit model is conditional on two factors:

1. Winning the bid. Section 4.4 describes how the probability of winning a bid is calculated. If the bid is not won the costs and profit for the proposed project are effectively zero (assuming that the cost of constructing the bid is regarded as an organisational cost not a project cost).

2. Delivery of an acceptable product. A feature of software projects (usually large projects) is that there is a non-zero probability of the project failing completely. Either the software product is never produced or the product is rejected by the client after initial deployment. The bidding team must estimate the probability of complete failure and the cost of complete failure.

Any profit model must allow for each of these conditions. In addition, it may be invalid to consider any left over contingency money as profit. It may be preferable to leave unused contingency in the portfolio contingency fund.

Assuming we use the hypothetical data shown in Table 2, the corresponding profit distribution is shown in Figures 13 and 14. These are based on 1000 iterations. Figure 13 is a bimodal distribution, the bimodality occurs because in some model simulations the contingency related events occur and in some they do not. Figure 14 shows the negative cumulative profit distribution. The cumulative distribution does not start at 1 to allow for the probability that the bid is unsuccessful. Figure 14 makes it very clear that even if the bid were successful, there is only a very small probability of the project making a profit.

In this example there is strong overlap between development costs (£90,000 minimum, £150,000 maximum and most likely £100,000) and client preferred price (£90,000 minimum, £180,000 maximum and most likely £120,000). Without a proper understanding of the relationship between vendor price and vendor costs, we might assume that this project has a high probability of success. However, the cost estimate does not include profit or contingency and the probability of success based on a realistic price is very low both in terms of bid success and in terms of project profitability.

5 A detailed bidding model

In this section we consider a more detailed model that considers the links between staff effort, costs and duration and the causes of contingency costs. The model discussed in this section is a budget driven model rather than a time scale driven or a time scale constrained model (see Section 4.5.1). If a budget driven model can be properly specified, it should not be too difficult to adapt the model to represent the other types of model.

The important elements of the more detailed model are discussed below

5.1 Estimated Costs and Delivery date

5.1.1 Estimated Costs

The estimated cost distribution is determined by considering:

- The costs associated with purchasing software hardware etc. These can be regarded as being known costs (i.e. are not subject to estimation error).
- The costs associated with staff effort. Staff effort must be converted from a time unit (e.g. days or weeks) to a monetary value (e.g. pounds sterling) based on a rate determined by the organisation. Staff effort can be modelled as a distribution with a

most likely value and upper and lower bounds. The distribution is often strongly skewed.
- The costs associated with management and clerical staff. These can be modelled as a percentage of staff costs.

The detailed model for estimated costs is shown in Figure 15.

5.1.2 Estimated Duration and Estimated Delivery Date

The date on which the application developed by a project will be delivered is determined from consideration of the expected duration of the project and the current commitments of the development organisation (see Figure 15).

The expected duration of a project is usually considered to be a function of the staff development effort. One possible model to determine duration is:

Duration (weeks) = Effort (weeks) × Adjustment factor /Average team size (4)

The adjustment factor is the amount of actual effort a person can devote to a project in one week. One week of staff effort does not equate to a calendar week for the following reasons:

- Allowing for paid leave, staff work about 42 weeks in each 52 week year.
- Staff usually spend part of their available working time on non-project activities, such as undertaking training, non-project quality assurance and quality control activities. For example, in organisations that use inspections, staff are often required to moderate inspections for projects they are not working on.
- Technical staff must usually perform some administrative work as well as their technical work, for example reporting to their line managers and completing time sheets. The costs of such time are allowed for in the overhead adjustment but it must be understood that the effort used in such activities is effort that cannot be applied to technical tasks.
- There are overheads if team members work on several projects simultaneously. For example staff who are assigned to two projects, nominally half time on each project probably contribute only one third technical effort to each. Note this effect does not occur if part-time staff work only on a single project.

Thus one week of technical effort equates to more than one calendar week. The adjustment factor should be 1.2 minimum to allow for holiday provisions and is more realistically in the region 1.3-1.7 to allow for non-project work, non-technical project work, and any multiple project working.

Note. Average team size is not a straightforward concept. Projects usually start with a few staff, build-up to a maximum level and then reduce staffing levels as the project enters the last development phase.

Note. There are other models such as Putnam's Rayleigh curve model that provide a means of relating variables such as effort, team size and duration (see for example, Londeix, 1987).

Estimating the likely duration of a project does not define the expected delivery date. The delivery date depends on the existing commitments of the software developers. In order to identify an appropriate delivery date, it is necessary to model the dynamics of the project portfolio to identify a time period within which the proposed project can be scheduled. The project portfolio should include all approved projects but should also allow for potential projects (i.e. projects for which bids have been submitted but the outcome of the bid is unknown). The allowance for potential projects should be weighted according to the probability that they will be approved. This provides a means of catering for an over-booking policy.

Building a dynamic portfolio model is beyond the scope of our current research project. Thus, the delivery date distribution can only be assessed from expert opinion. In this case, the duration estimate can be used to obtain the minimum value for delivery date distribution.

5.2 Contingency

Contingency is calculated from the estimated extra costs associated with unplanned work (see Figure 16). Contingency costs arise from two causes:

1. The need to perform additional unplanned work in order to complete the project. The usual reasons for extra work are either that the scope of the project has been underestimated so some tasks were ignored or underestimated, or that the project was more difficult than expected so that the task effort was systematically underestimated.
2. Penalties accruing to late delivery of the software product. Late delivery can result because the need to undertake unplanned work causes an overrun, or because subcontractors delay delivery of required software or hardware, or because there are insufficient staff available to work on the project. The greater the amount of overbooking the greater the probability that staff will be unavailable when required.

As discussed in Section 4.2.3, in order to obtain a contingency cost value, a values is selected at random from the contingency distribution and multiplied by the probability that the contingency occurs. The contingency should be adjusted up or down in accordance with the current status of the organization's portfolio contingency fund. More research is required to identify an appropriate way of modelling the relationship between the contingency adjustments required for a particular project price and the portfolio contingency fund. Until such research is complete, the contingency adjustments can be modelled as discussed in Section 4.2.3

One way in which extra effort and delay costs can be modelled is discussed below.

5.3.1 Estimating unplanned additional effort

Additional unplanned staff effort is modelled as random variable. The distribution of the random variable must be specified by the software development group. It would be based on an assessment of the implication of systematic bias (towards underestimation) in the original effort estimates.

Kitchenham and Linkman (1997) suggest the extent of unplanned effort could be estimated by considering the impact of initial estimating assumptions being invalid. Thus, we have one estimate of staff effort based on the most likely assumptions which we use for planning and pricing (the planning estimate) and a second estimate of staff effort based on an alternative set of assumptions (the alternative estimate) that we use for contingency planning. The estimate of additional effort required under alternative assumptions is obtained from the equation:

Additional effort=Alternative estimate-Planning Estimate (5)

If there are several different possible causes of extra effort (e.g. both underestimating project scope and underestimating technical difficulty), separate estimates can be obtained for each cause and their impact on contingency assessed separately. That is, we would have many different events each with an associated distribution of impact costs and probability of occurrence. The contingency for each event can be calculated (by multiplying a value taken at random from the cost distribution and multiplied by the probability of occurrence) and the total contingency for a project assessed by summing all the individual contingencies.

If the alternative assumptions were actually true, the additional effort required to complete the project will also affect the distribution of delay costs. If additional effort is non-zero, extra elapsed time will be needed to perform the extra work. This will result in time delays as discussed below.

5.3.2 Estimating delay costs

Delays can be caused by:

- Project staff shortages. If a project was based on an invitation to tender submitted under conditions of excessive over-booking, there is a strong possibility that there will not be staff available to perform technical work according to the originally envisaged plan.
- The necessity to do unplanned extra work (effort-induced delays).
- Non-delivery of subcontracted sub-products (supplier delays). Supplier delays are caused by delays in the delivery of hardware or software components.

For simplicity we assume that delays caused by suppliers or staff shortages have no budget implications. However, we note that hiring staff or employing subcontractors as a response to staff shortages does have budget implications.

The way in which these delays can be modelled is discussed below.

5.3.2.1 Staff shortage delays

Delays caused by staff shortages can be assessed using a model relating effort and team size to duration. Equation (4) can be used to assess the additional duration needed to perform additional tasks as well as the expected distribution of the overall model.

Like estimating additional effort, we have one estimate of average team size, based on the most likely set of assumptions for the project, on which expected delivery dates are calculated (i.e. the planned team size). We also have a second estimate of average team size based on the probability that staff will not be available when required (i.e. the restricted team size). The restricted team size would be evaluated by considering the impact on average team size if our planning assumptions were invalid.

To estimate the effect of staff shortages, the expected duration based on the planned average team size should be compared with the expected duration based on the restricted team size. Thus:

Staff shortage delay = Expected duration given planned average team size -
Expected duration given restricted average team size (6)

The expected duration for both average team size estimates can be calculated using Equation (4).

Note. A more detailed method of modelling staff shortages would consider staff requirements over the expected life time of the project and compare that with staff availability distribution based on the total available staff and their allocation to other projects and potential projects. As noted in section 5.2.2, this would require a dynamic portfolio model and is beyond the scope of this model.

5.3.2.2. Effort-induced delays

Effort-induced delays arise when extra technical effort is needed to produce the required product. Additional effort may be required as result of underestimating the scope of the project or underestimating the difficulty of the project. The various causes of additional effort can be considered independent, so the individual elements are additive (see Section 5.3.1).

In order to calculate the impact of effort-induced delays, Equation (4) can be used to assess the additional time required to do the extra work. Calculation of effort induced delays must be coordinated with calculation of staff shortages (see 5.3.2.1) in order to ensure that the most appropriate estimated average staffing level value is used.

Note. There are organisations that assume extra effort can be absorbed without requiring extra elapsed time by means of adding staff or encouraging overtime. However, we agree with Fred Brooks view that adding extra staff to a late project makes it later (Brooks, 1985), and we are aware of studies in other disciplines that indicate that tired staff make more mistakes and work less effectively than fresh staff. Therefore, this model assumes that unplanned work takes extra time.

5.3.2.3 Supplier delays
Supplier delay should be modelled as a random variable. If a project has no external dependencies, the expected delay due to suppliers will be 0. However, for any project with external dependencies there will be a non-zero probability of supplier delay. The distribution of the supplier delay variable must be determined by the bid team.

5.3.2.4 Assessing total delay
Delays caused for different reasons do not necessarily sum. For example, effort-induced delays may occur at the same time as supplier delays. Therefore in order to assess total delays we need to assess the extent to which effort-induced and staff-shortage delays overlap with direct delays:

$$\text{Total delay} = \text{Supplier delays} + \text{Effort-induced delays} \times \text{Overlap1} + \text{Staff shortage delay} \times \text{Overlap2} \quad (7)$$

The Overlap variables can be represented as random variables from independent distributions each with a maximum of 1 and a minimum of 0. The distribution should be specified by the bid team.

5.3.2.5 Converting delay to costs
Delays are measured in a time unit (e.g. weeks) and are converted to costs by using penalty distribution. The penalty distribution should be obtained from discussions with the client (or from the marketing or sales department).

5.3.3 Detailed contingency model
Based on the above discussion, a detailed model of the contingency costs is shown in Figure 16. Note for simplicity we have not included a breakdown of the sources of additional effort, nor have we included the administrative effort associated with the additional effort.

5.4 Summary of model variables
The model variables are summarized in Table 3. It defines each variable, indicates how variable values are determined and identifies the organisational role responsible for deciding any fixed values or specifying the distribution of random variables. It also indicates whether a variable value is specific to a particular project (such as the final price), or applies to all projects (such as a strategic fixed value for profit level), or is dependent on the current status of the portfolio of projects (such as the contingency risk level).

Table 3 The variables used in the model

Variable Name and unit	Definition	How variable is determined	Variable Scope
Adjustment Factor	The amount by which effort is expanded to map to elapsed time	Bidding Team	Organisation
Administrative costs (£)	The costs of administrative staff.	Estimated staff costs × Overhead Rate	Project

Contingency (£)	The price element used to cater for unplanned events	Calculated from the distribution of unplanned costs and the agreed contingency level.	Project
Contingency fund status	The current status of the contingency fund	Assessed in terms of expected value of the contingency fund over the life time of the project	Portfolio
Probability of occurrence	The probability that the contingency fund will be needed	Assessed during the risk analysis used to determine the contingency distribution	Project
Competition adjustment	A weight used to adjust the profit level according to the level of competition for the project.	Determined by marketing on behalf of the bid team	Project
Day (week) rate (£)	The average daily cost of technical staff	Finance department	Organisation
Delivery Date	The estimated date for delivery of the application.	Calculated by adding the duration to the agreed start date.	Project
Delivery Delay Penalty costs (£)	The costs of the expected delay	Calculated from a distribution of penalty costs defined by the client (or marketing department)	Project
Difficulty	The extent to which the difficulty of the project may have been underestimated.	Assessed by the bid team.	Project
Duration (weeks/ months)	The estimated time it would take to perform the project	Estimated using model (3) or technical staff expert opinion	Project
Duration risk level	The risk level used to determine duration and hence delivery date from the duration distribution	Determined by senior managers on behalf of the bid team. It may be adjusted in the light of the organisation's expected staffing profile	Organisation
Effort induced delays	Extra time needed to perform any unplanned work.	Duration (weeks) = Extra Staff Effort (weeks) × Adjustment factor /Actual Average team size	Project
Estimated cost (£)	The total costs associated with the project.	Sum of known costs, administrative costs and staff costs.	Project
Estimated Staff Costs (£)	The costs associated with technical effort	Estimated Cost * Day (Week) Rate	Project
Estimated Staff Effort (days or weeks)	A distribution representing the amount of technical effort required for the proposed project.	Assessed by technical staff on behalf of the bidding team	Project
Extra Staff Effort (days)	Effort required to perform unplanned work	A conditional distribution of costs estimated by the bidding team. The bidding team must also assess the conditional probability that unplanned work is necessary	Project
Extra Staff costs (£)	The costs associated with any unplanned work.	Extra staff costs = Extra Effort × Day rate (£)(100+Overhead	Project

		rate)/100	
Importance adjustment	A weight used to adjust the profit level according to the strategic importance of the project	Determined by senior management	Organisation
Known costs (£)	The costs associated with purchase of project tools (software and hardware)	Finance department	Organisation
Organisation staffing profile	The staffing levels of the organisation during the timescales of the proposed project. The staffing levels take into account confirmed projects and proposed projects.	Determined by senior managers on behalf of the bidding team	Organisation
Overhead rate (%)	The percentage used to increase technical staff costs in order to allow for administrative staff costs.	Finance department	Organisation
Overlap1	The extent to which effort induced delays overlap with Supplier delays	Distribution specified by bidding team	Project
Overlap2	The extent to which staff shortage delays overlap with Supplier delays	Distribution specified by bidding team	Project
Price (£)	The price to be used in the final bid.	Sum of Contingency, profit and Estimated Cost (at given Risk Level)	Project
Probability of successful bid	The probability that the bid will be successful for given price and delivery date.	The individual distributions for price and delivery date are determined by marketing department on behalf of the bidding team. The joint probability is obtained by multiplying the two probabilities.	Project
Profit	The element of the price representing the profit the organisation expects to obtain from the project.	Calculated as a proportion of the estimated cost weighted according to the importance of the project and the extent of competition.	Project
Profit level	The proportion of costs used to calculate profit.	Determined by senior management	Organisation
Risk level (% or probability)	The probability level used to determined the Estimated Costs	Organisation policy or senior management opinion	Organisation
Scope	The extent that the scope of the project may have been underestimated	Assessed by the bid team.	Project
Staff shortage delay (weeks)	The expected number of weeks that the project will be delayed due to staff shortages	Staff shortage delay = Planned duration (based on planned team size) - Expected duration (based on expected team size)	Project
Staff Shortfall	The expected number of	A distribution assessed by the	Portfolio

(people)	people that will be unavailable for the project	portfolio manager in behalf of the bidding team	
Supplier delay	The expected time delay due to external dependencies	A distribution assessed by the bidding team.	Project
Team size (people)	The estimated average number of people working on the project	Assessed by technical staff on behalf of the bidding team	Project
Total Delay	The total delay due to unplanned events	Total delay = Supplier delays + Effort-induced delays×Overlap1 + Staff shortage delay×Overlap2	Project

6 Model Validation

It is important to consider to what extent the bidding model can or cannot be validated. Glen Koller (2000) points out that risk models to support decision making are difficult to validate since "You rarely, if ever, have the opportunity to know the results of the road not taken". In his view the only validation possible is to decide whether decisions based on the model were overall good decisions for the organisation.

Koller's arguments about validation seem reasonable. Thus, the validation exercises that can be attempted for the model can be defined as a three stage process to determine:

- How successfully the model meets its requirements.
- Whether software managers and engineers agree that the model is an acceptable representation of the software bidding problem.
- Whether software managers find the model helps them understand the bidding process and the implications of their estimates and assumption.

The third step in the evaluation process requires that the model be adopted by an organisation and its use monitored. This would be unlikely to occur unless the model was considered valid according to the first two criteria.

The second stage of the evaluation process could involve the following activities:

- a survey of appropriately qualified software personnel
- examples of the use of the model for various scenarios.

Such an evaluation would only be appropriate if the model was valid according to the first criterion. Since this is an initial formulation of a bidding model, the only form of validation provided in this document is a summary of the ways in which the model meets each of its requirements. This is shown in Table 4. Table 4 refers to the top level model shown in figure 7.

Table 4 The extent to which the model meets its requirements

Requirement	How the requirement is met
Assistance with bid/ no-bid decision making as well as pricing.	The probability of success can be used to assess whether or not it is worth bidding. However, using the model to determine the profit distribution gives the clearest indication as to whether or not to bid

	for the project
The impact of over-booking strategies.	The impact of over-booking is addressed during the conversion of expected duration to a delivery date.
Consideration of both cost and time scale on pricing decisions.	Cost and time scale are both inputs to the assessment of the probability that the bid is successful
The impact of competition on price decisions.	Competition is assumed to affect the profit element of the price.
The impact of category 1 risk i.e. uncertainty in cost (effort) estimates.	The level of category 1 risk acceptable to the organisation is used to decide the cost value used to construct the price.
The impact of category 2 risk i.e. the amount of contingency required to allow for unplanned tasks and delays.	Category 2 risk is assessed in terms of the probability that the contingency situation occur and the distribution of costs if it does occur.
The impact of category 3 risk i.e. the probability that the proposal will be rejected and/or the bid will win but the project will fail	The pricing model outputs the probability of the bid being successful. If the model is run as a profit model, the implications of all categories of risk can be assessed.
The impact of the project portfolio on the bidding process should be specified	The impact of the portfolio on the bidding process is assumed to be via two factors: 1. The status of the contingency fund is assumed to influence the contingency value. 2. The staffing profile depends on the extent to which staff are already committed to other projects or other potential projects.

Table 4 suggests that the model addresses all its requirements. However, the model does have some limitations:

1. A lot of work needs to be done before the modelling approach gives any help with the bid/no-bid decision. It may be that a rule-based model as proposed by Dawood (1996) is more suitable for initial decision making.
2. Our current models of the impact of the project portfolio on delivery date and contingency are very simplistic. We require detailed models both of the impact of staff availability over the planned duration of the project (allowing for potential projects as well as confirmed projects), and of how the current state of the contingency fund should influence the contingency risk level. However, such models are beyond the scope of the current research project.

7 Conclusions and Future work

Koller's method of developing risk models is very flexible (Koller, 2000). It can be used to model different types of decision and risk problems in many different industrial situations. We have been able to use the method to specify the contributing-factor diagram for a generic software bidding model. One benefit of this modelling approach is that it is easy to model a situation at different levels of granularity. Thus, we initially specified a top level model and then expanded some aspects of the model into a more detailed model.

An important aspect of our bidding model is that it attempts to define the information required from the different organisational groups involved in the bidding process. In our experience, practitioners generally find it difficult during bid preparation to identify what information is required from which organisational role and how such information should be used constructively. For example, we have often heard software engineers complain that their estimates are overridden by senior managers or marketing staff. In our model we try to make it clear that the marketing department estimates client requirements/ preferences for price and delivery date, while technical staff estimate costs and delivery dates based on work content. Both estimates are valuable in the bidding process but it must be recognised that they are estimating different things. Senior managers must make the final decisions about bidding and pricing. They can only make informed decisions if they have both types of estimate and can assess the risks, for example profit risk, inherent in any specific selection of price and delivery date.

It is clear that our models rely on the expertise of their users in terms of their ability to specify the distribution of various random variables. It can be argued that given all the information must be supplied by the users of the model, the model itself is not very useful. However, the utility of the model needs be assessed in terms of the extent to which it helps clarify the implications of its user's knowledge and opinions.

Further work will concentrate on specifying some plausible scenarios in order to specialize and then animate the model. We need both to confirm that all the links between model elements are properly specified and to confirm that the high level model and the more detailed model give plausible results.

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Figure 1 Contributing-factor diagram for Terrorism Risk Model

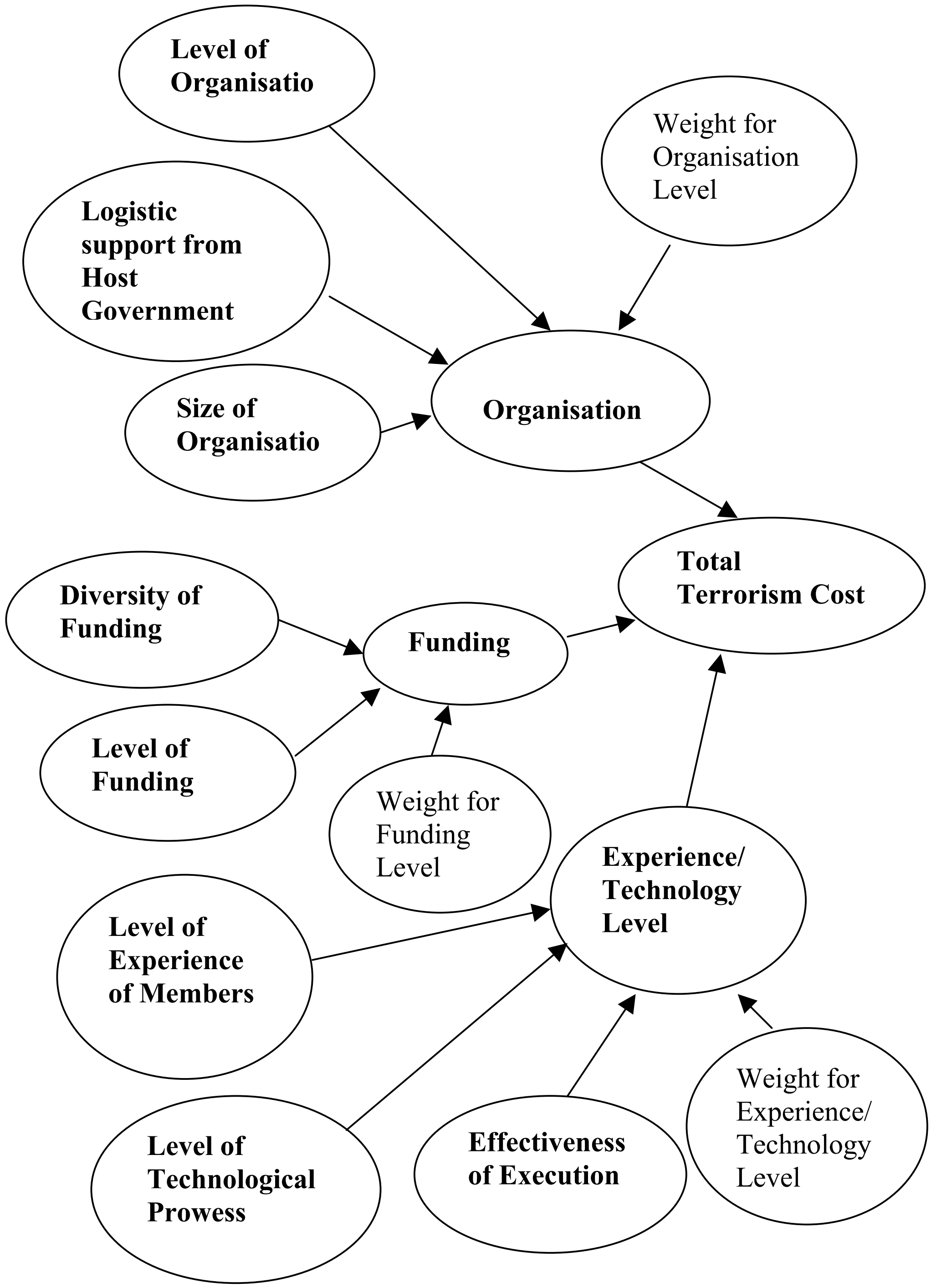

Figure 2 Distribution of the level of organisation

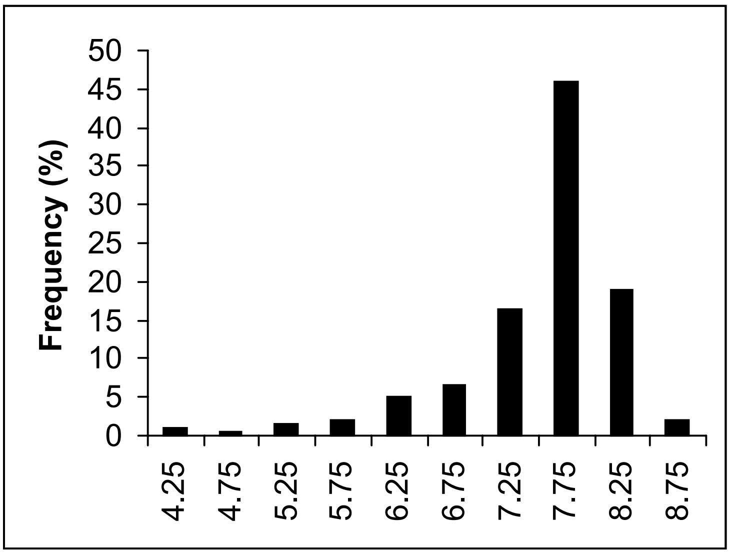

Figure 3 Distribution for level of member experience

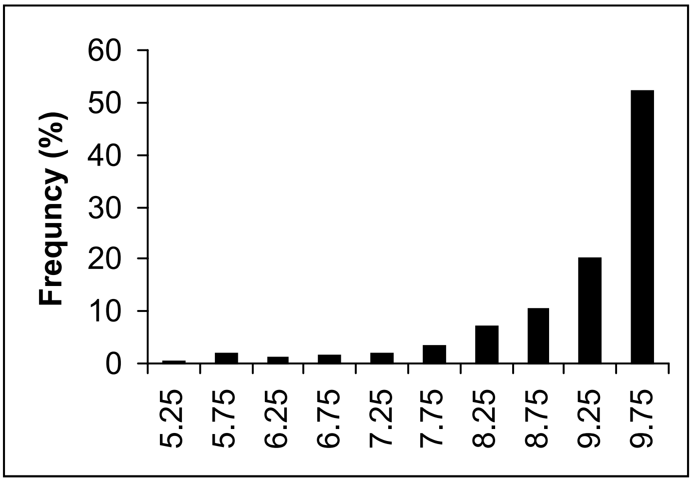

Figure 4 Distribution of the level of technical prowess

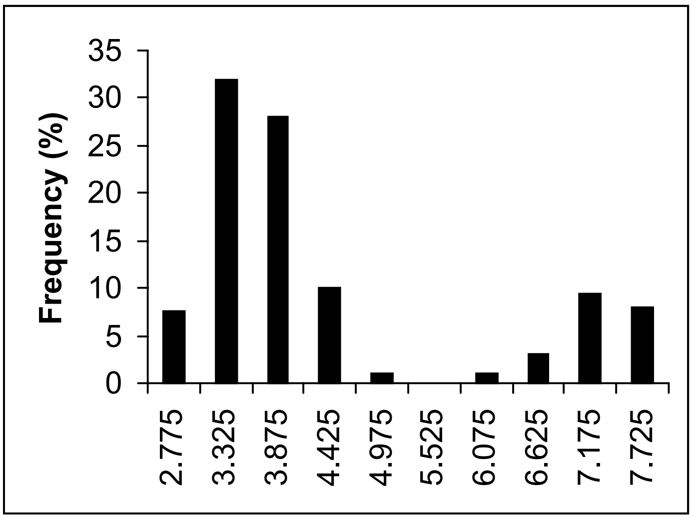

Figure 5 Cumulative probability of the total weighted risk

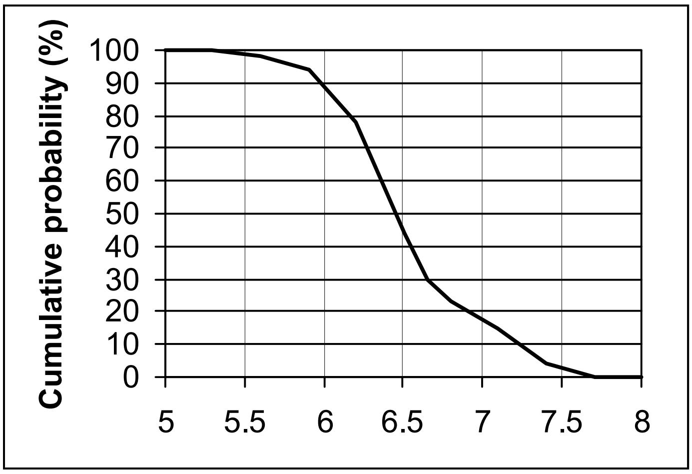

Figure 6. Cumulative frequency plot with ERWR area shaded

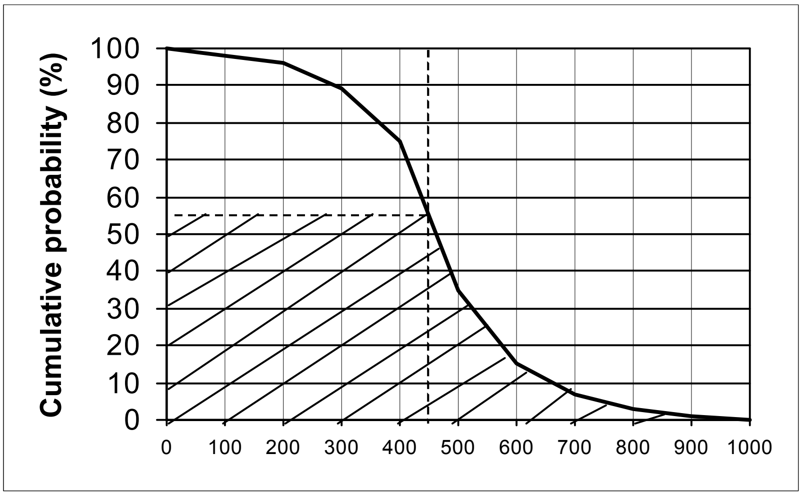

Figure 7 Outline bidding model

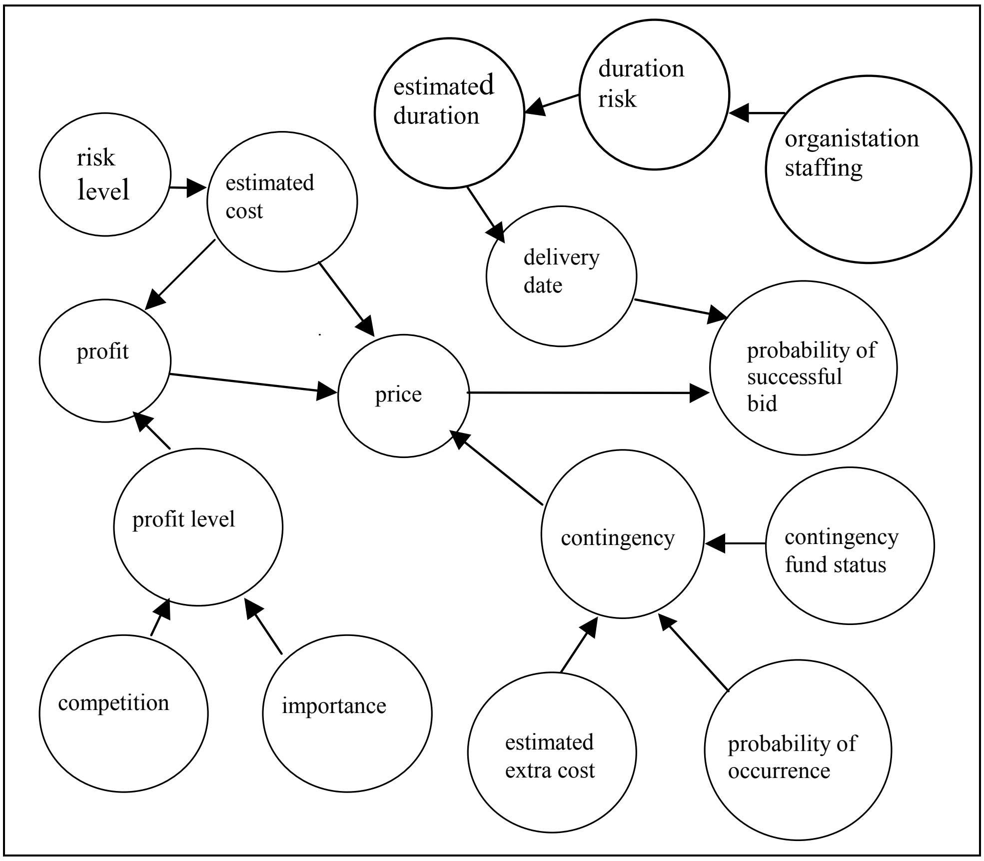

Figure 8 The delivery data distribution defined by the software development group

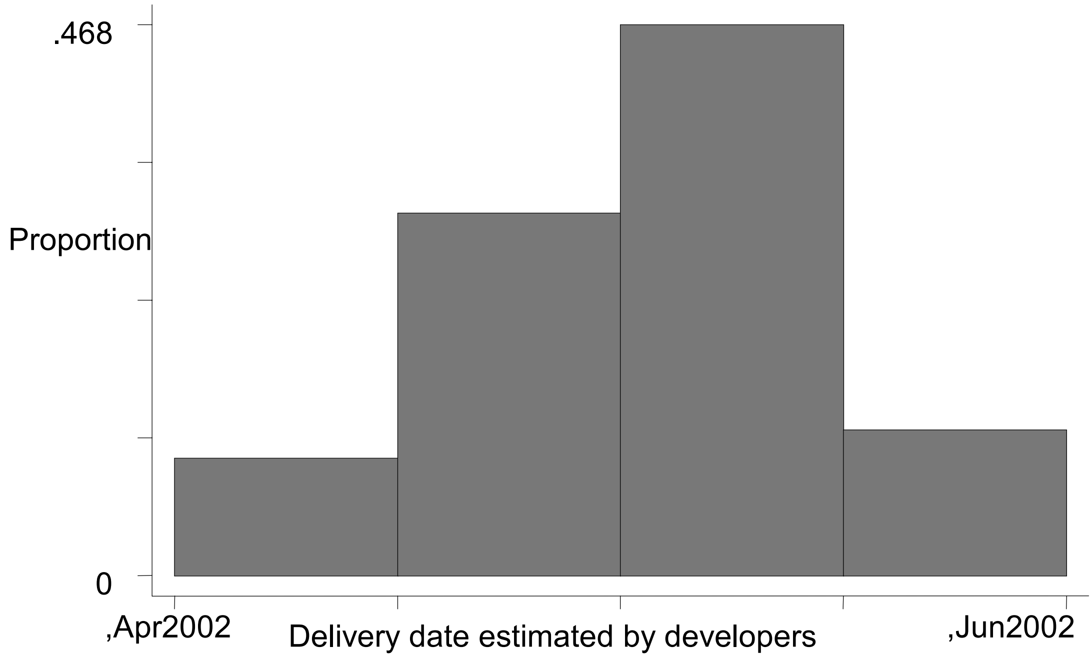

Figure 9 The price distribution defined by the software development group

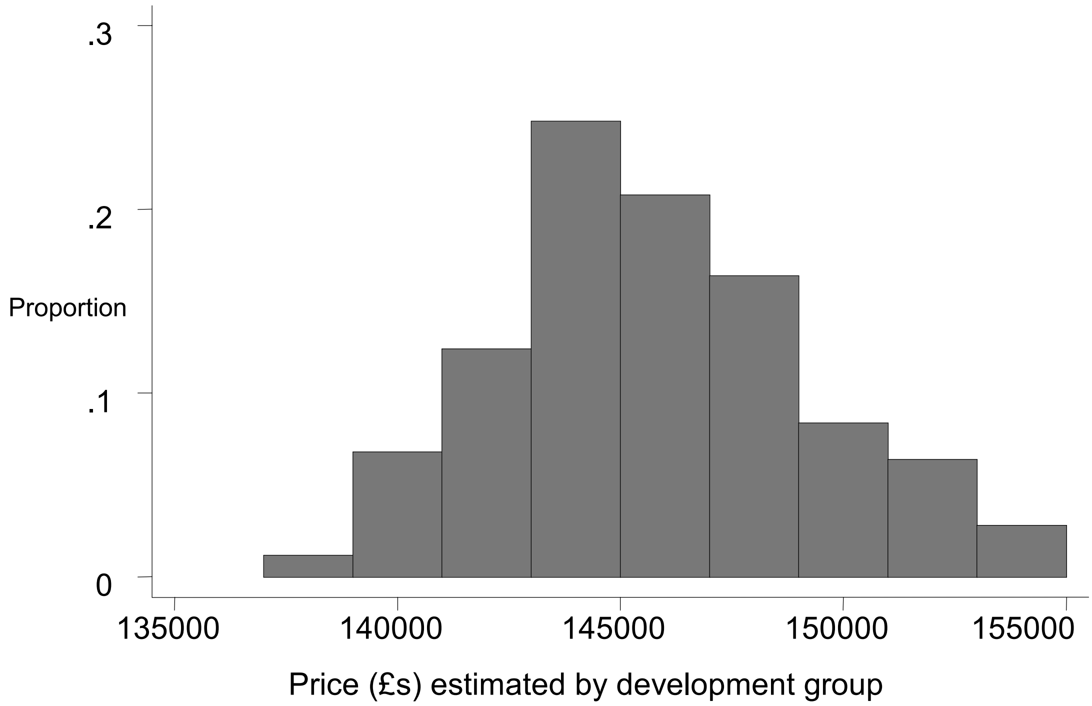

Figure 10 The delivery distribution preferred by the client (assessed by the marketing department)

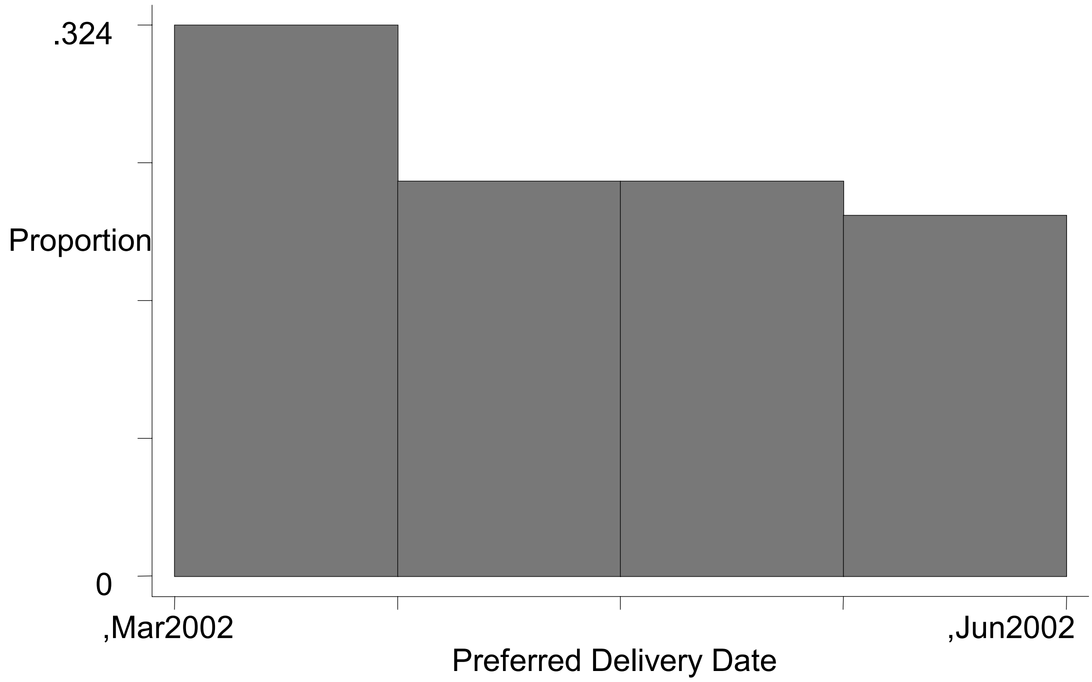

Figure 11 The price distribution preferred by client (assessed by the marketing department)

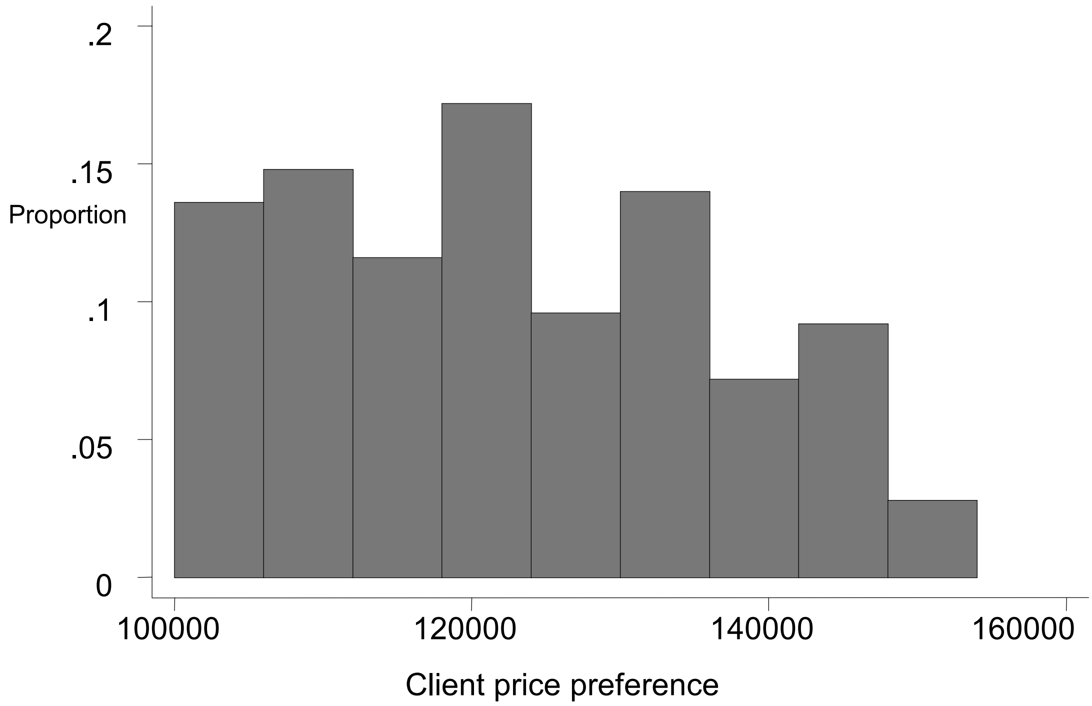

Figure 12 The inverse cumulative distribution of delivery date (development and marketing)

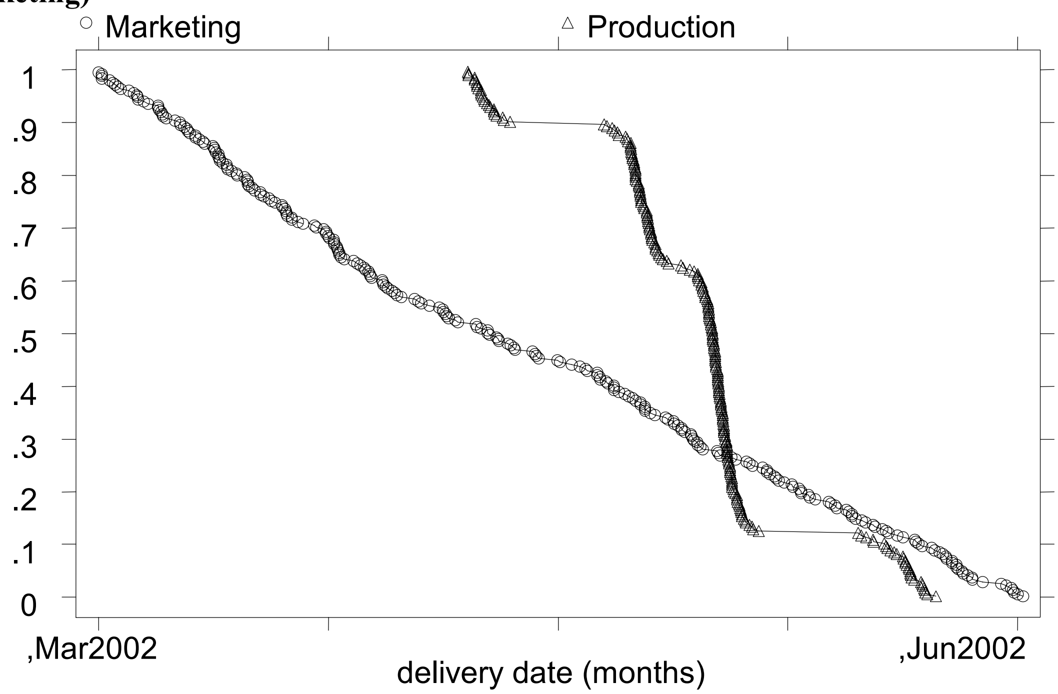

Figure 13 Profit distribution

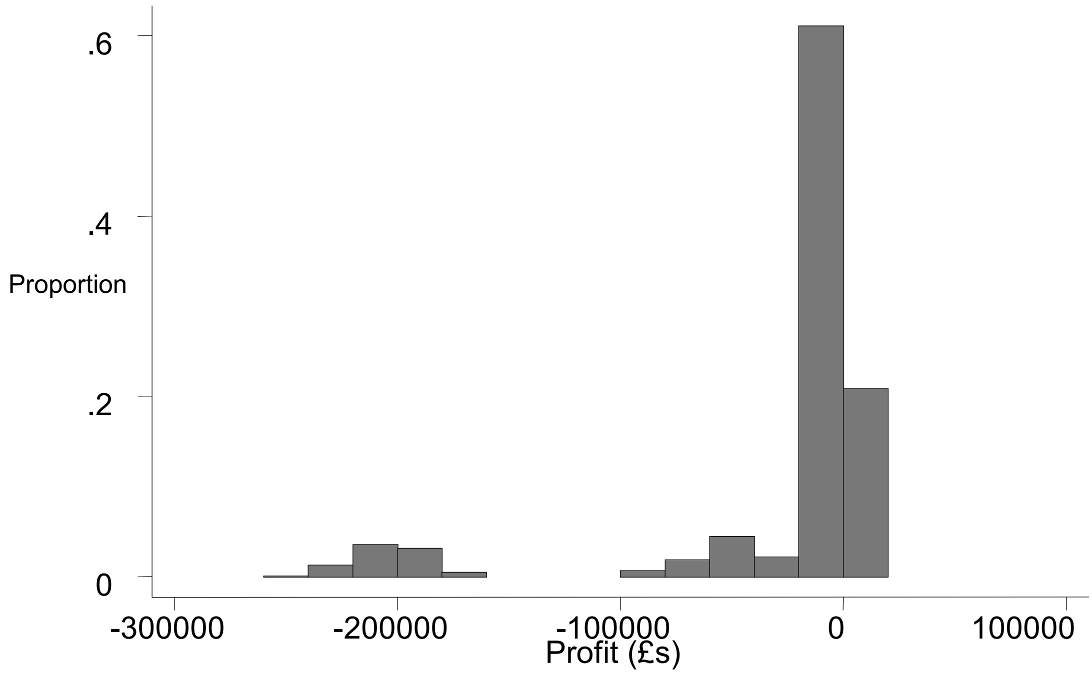

Figure 14 Inverse cumulative profit distribution

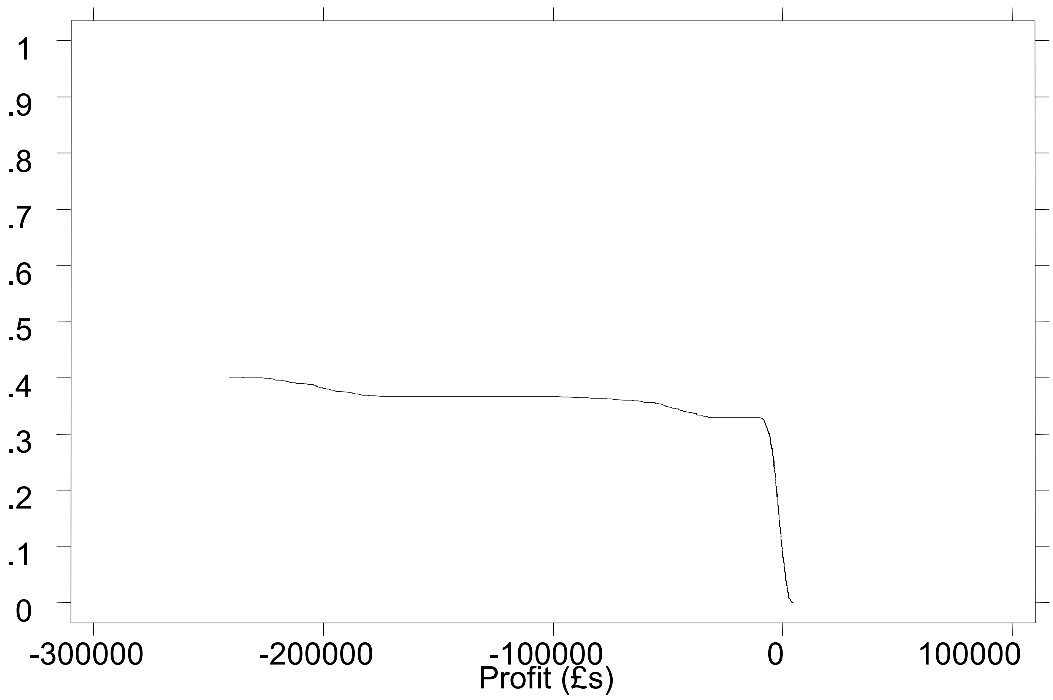

Figure 15. Detailed model for estimated costs and delivery date

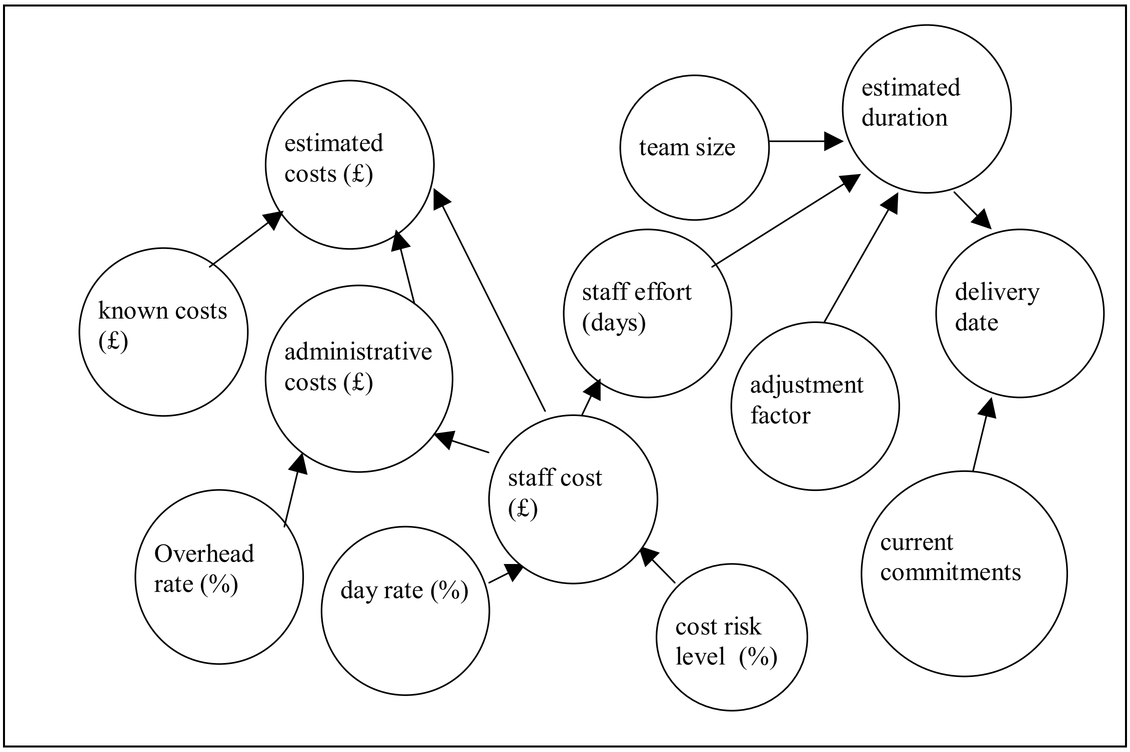

Figure 16 Detailed model of contingency