ANALYSIS OF RISK IN CONSTRUCTION AUTOMATION INVESTMENT

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Abstract: The decision to invest in construction automation rests upon the financial and intangible benefits. Although a selection of associated costs may be obtained from suppliers or estimated using managerial judgement there is an inherent level of uncertainty surrounding the annual cash flows. Analysis of investment risk may play an important role in the introduction of automated construction technology to UK construction engineering. Stochastic risk simulation may be applied to analyse the uncertainty surrounding the investment decision faced by UK contractors and plant hire firms. Using Monte Carlo sampling techniques, risk profiles have been generated for a tele-operated system from a financial model replacing discrete estimations with a range of subjective probability density functions. It is concluded that there appears to be downside financial risk associated with the decision to invest in the chosen example system and that additional objective data is essential for accurate financial risk analysis. In opposition with the down-side risk associated with the chosen system, the non-tangible rewards appear to favour investment in automated construction technology.

Keywords: Automated construction technology, financial risk, generic appraisal model

1 INTRODUCTION

Within an investment appraisal context risk is defined as the uncertainty surrounding the input variables to the decision model. Vagueness concerning cash flow estimates and the calculated performance measure is generated from utilising discrete estimations for investment appraisal analysis. Cash flows are estimates of quantities whose true values are uncertain because they will be determined in the future. Probabilistic risk analysis is a powerful tool for investigating investment decisions, which rely upon predictions of future cash flows. Stochastic simulation, in the form of Monte Carlo simulation assumes that discrete investment appraisal input parameters are replaced with probability density functions. The need for simulation is generated by "*man's uneasing quest for knowledge about the future*" [1].

The term 'risk analysis' originated with Hertz [2]. Hertz's method aims to aid executives in key capital investment decisions by furnishing them with a realistic measurement of embodied risk. Rather than predicting single estimates for inputs to investment decision models, Hertz proposed that probability distributions replace the discrete estimates and that these input distributions are sampled to generate an output 'risk profile' for the chosen performance criterion. Hertz believed that "*the courage to act boldly in the face of apparent uncertainty can be greatly bolstered by the clarity of portrayal of the risks and possible rewards*"[2]. The essence of probabilistic risk analysis is to provide the investment analyst with a means to look ahead at possible future outcomes and evaluate whether the investment should be approved. With regards to construction automation, thousands of possible cash flow scenarios can be modelled to give an indication of the inherent financial risk.

The topic of review within this paper is the application of probabilistic risk analysis to the decision of construction automation purchase and utilisation. According to Baker *et al* [3] the construction industry perceives risk as "*mainly financial*". Investigation of the financial risk associated with the introduction of automated construction technology is necessary to analyse the risk surrounding the investment and utilisation decision. Edwards and Bowen [4] concluded that technological risk analysis is an important direction for research into risk management in construction. The purpose of this work is to analyse the financial risk incorporated within the investment, organisation and introduction of automation to UK construction and civil engineering. The authors propose a generic financial appraisal model to examine the financial risk associated with construction automation investment.

Objective probabilities are difficult to obtain from the construction industry, where each project is unique [5]. If objective data is not available for determining probability distributions for inputs to a risk analysis model, then subjective data, based upon managerial judgement, may be utilised.

Cash flow data may be subject to variability and uncertainty, due to unfamiliarity with the costs associated with automated construction technology. Probabilistic risk analysis will provide a means for including this uncertainty within NPV investment appraisals. Risk measurement will provide those concerned with the decision to invest in construction automation with awareness of the risks associated with the investments return; an insight into the most sensitive costs or savings to the overall profitability of the investment; and assistance in making a more effective investment decision. The following probabilistic financial risk analysis model utilises probability distributions to model the tangible costs associated with the utilisation of a currently available tele-operated automated construction system.

2 TRADITIONAL INVESTMENT APPRISAL TECHNIQUES

Traditional investment appraisal techniques may cause automated construction systems to be rejected as a viable investment decision. Simple risk adjustment techniques contain "*assumptions which may not be easily understood by managers and could lead decision makers to accept decisions against their original intentions*" [6]. The traditional Net Present Value (NPV) method for investment appraisal generates results, which represent only a few points on a continuous curve of possible combinations of future occurrences.

Traditional investment feasibility analysis uses discrete (single value) estimates for the values of future cash flows over the economic life of a project. If uncertainty surrounds these cash flows, utilising a discrete subjective estimate may lead to erroneous decisions based upon the calculated NPV. It is easier to predict a range for an estimate rather than a single value. Ranges are estimated through the derivation of probability density functions.

The discount rate for a NPV analysis is generally based upon the rate of interest. Generally the base interest rate does not represent the requirements of company shareholders. Shareholder preference should be considered when deriving the discount rate to be used in an NPV investment appraisal. The authors recommend the utilisation of the Capital Asset Pricing Model.

3 THE REQUIRED RATE OF RETURN/DISCOUNT RATE

More recently, "*refined financial risk analysis*" [7] incorporates stochastic simulation and capital asset pricing theory. The principle asset pricing theory for the last twenty years has been the Capital Asset Pricing Model (CAPM) developed by Sharpe [8]. Kulatilaka [9] recommends the use of the CAPM to derive an "*appropriate discount rate, from which managerial subjectivity is reduced*".

The Sharpe CAPM equation is as follows:

$$E(r_{proj}) = r_f + [E(r_M) - r_f]\beta \qquad (1)$$

Where $E(r_{proj})$ is the project rate of return; r_f is the risk free rate of return (the return on three month government treasury bills); $[E(r_M)-r_f]$ is the market risk premium; and β is the measure of sensitivity of the return on the security to the return on the surrogate market portfolio (FTSE All Share index).

The return on three month treasury bills was obtained from the Bank of England Monetary and Financial Statistics Division. A value of 6.03125 % was used for the following analysis. The value of the market risk premium, 9.15%, was based upon the *ex-post* average for the UK from 1914 to 1984 [10]. Adopting a historic risk premium is justified on the basis that although expected returns should be used they cannot be measured. The beta (β) coefficient for the UK construction industry has been calculated by performing a regression analysis on the returns of an industry portfolio against the returns of the FTSE All Share index over a period of five years (1993 to 1998). The value obtained from the five year market model and used in the analysis was 1.28.

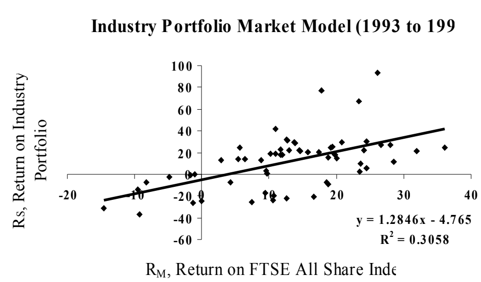

Figure 2. Derivation of β for the CAPM derived NPV discount rate

$$E(r_{proj}) = 6.03125 + [9.15]1.28$$
$$E(r_{proj}) = 17.743\%$$

A generic rate of return for investment within the UK construction industry was calculated using equation (1):
The calculated rate of return is used as a project rate of return or discount rate for the NPV investment appraisals. This value reflects both market risk and also includes the preference of company shareholders. It is assumed, to assist exposition, that the discount rate is constant throughout the life of the project.

4 SIMULATION AND RISK ANALYSIS

Construction managers are concerned with the probability that the NPV value might be less than zero, in which case the investment or project would not be economically feasible. This probabilistic information is useful in investment decisions that involve trade-offs between profitability and risk for go/no-go decisions.

Within a risk analysis model cash flow is broken down into subsystems (input variables) described by probability density functions. In the absence of objective historical data, experienced estimators may generate subjective data. Subjective probability distribution functions are justified on the basis that estimates are founded upon experience which included historical cost figures [11]. The concept of subjective probability is "*not just opinion, it is orderly, consistent opinion*" [12]. Although there will be a natural inclination to base the input probability distributions upon objective data, subjective probability distributions are more easily produced as it is "*easier to guess with some accuracy a range rather than a specific* [discrete] *single value*" [13].

5 MONTE CARLO SIMULATION

Monte Carlo sampling techniques are entirely random- that is any given sample may fall anywhere within the range of the input distribution. Samples are more likely to be drawn from areas, which have a high probability of occurrence.

To generate a risk profile for the chosen output criterion, each of the input probability distributions are sampled. The computer program (@Risk Version 3.5.2 1998 and RiskView Pro) generates a random number between 0 and 1 for each input distribution. This random number corresponds to a single value on the cumulative input distribution. Once a value is returned from each input distribution, the NPV for the proposal is calculated and stored as one 'iteration'. A number of iterations, e.g. 10000, are executed to determine the risk profile for the output criterion.

6 PERFORMANCE CRITEREON

The chosen performance criterion for the risk analysis model is the Net Present Value. It is generally agreed that the NPV method is superior to the internal rate of return (IRR) method [14]. Since the objective of the firm is to maximise shareholder wealth, then managers entrusted with these funds should not invest in projects unless the expected returns exceed those available to shareholders in the capital markets. NPV results predict the likely net effect of a project upon the market value of the firm.

The NPV calculations have incorporated allowances for corporate taxation, so as to account for the effects of taxation upon the investment appraisal decision [15].

The net present value (NPV) of an investment project is the sum of the net discounted future cash flows:

$$\sum_{t=0}^{n} \frac{A_t}{(1+r)^t} \qquad (2)$$

Where A_t is the projects cash flow (either positive or negative) in time t (a value from 0 to n, where n represents when the economic life of the machine expires) and r is the annual rate of discount or the time value of money, which is assumed to remain constant over the life of the machine [16].

The NPV decision rule for project investment analysis is that if the NPV is greater than zero the project should be accepted, if less than zero the proposal should be rejected. It is assumed within the following risk analysis that the output performance criterion can only be measured in terms of standard deviation if it is normally distributed around the mean value

The possibility of a negative NPV can be gauged from the area under the output probability density function that lies to the left of the line that denoted an NPV of zero. Whether such a level of risk is acceptable "*depends upon the risk aversion*" [17] of the investment decision-maker. The results of a risk analysis will allow the decision-maker to quickly appreciate the possibility of the project NPV resulting in a negative value.

7 CHOICE OF PROBABILITY DISTRIBUTION FUNCTION

There are many suggestions within the literature of risk analysis as to the type of probability distribution to be used for input subsystems for Monte Carlo and Latin Hypercube based risk analysis. Chau [18] concluded that the use of the triangular probability density function results in an "*upward bias in the probability of exceeding the most likely estimate*". The positively skewed triangular probability distribution systematically overestimates the probability of exceeding the most likely estimates. This results in a substantial overestimation of the risk exposure.

The most widely assumed probability density function for modelling construction cost data is the beta distribution [19]. Reasons for using this distribution type rest on its versatility, which enables it to approximate a wide variety of probability distribution shapes. The subjective beta distribution is useful for modelling when actual data is absent. Skewed subjective beta and triangular probability distributions have been utilised (Cost-positive (right) skew, Savings- negative (left) skew) to depict the greater concern with the probability of costs being closer to the maximum estimate and the probability of savings being closer to the minimum estimate.

Normal, triangular and uniform distributions have also been assumed in the analysis for independent random variables to assess the sensitivity of the investment NPV range to changes in the shape of the probability density function of costs/benefits.

The subjective beta input distributions utilise four values consisting of a minimum, mode, mean and maximum estimate. Normal input distributions require an estimate of the mean and standard deviation. Triangular probability distributions require an estimate for the minimum, most likely (mean) and maximum values. Discrete estimates were used to form the basis of the input probability distributions (Table.1). The discrete estimates were formulated using traditional labour costing procedures [20] where appropriate. Uncertain cash flows were estimated using 'best guess' approximations. The authors acknowledge that these discrete estimates may not accurately reflect the realised costs and savings of the chosen system.

Input Cost	**Discrete Estimate (£'s)**
Purchase	15000
Set-Up	2500
Labour Savings	28987
Material Savings	1000
Energy/Fuel	1500
Maintenance	3000
On-site Transfer	2650
Technicians Pay	2000
Operators Pay	19568
Inter-site Transport	600
Resale Value	0
Cost of Repairs	1000

Table.1 Discrete Cash Flow Estimates

8 INPUT PROBABILITY DENSITY FUNCTIONS & INTERDEPENDENCE

Input or subsystem independence is often assumed due to the complications involved in modelling dependence. Chau [19] suggests that illogical results follow directly from the assumption of independence. Independent sampling procedures produce accurate means, but over estimations in the standard deviations. This generates a serious problem with the technique, since the essence of risk analysis is to indicate the variability of the performance measure (i.e. using the standard deviation of returns).

It is assumed that there will be a correlation between maintenance and associated costs, i.e. technicians pay, transfer costs and the cost of repairs. Correlation is not modelled within the probabilistic risk analysis model outlined in this paper. Analysis of the effects of correlation and dependence is out with the scope of this paper, although, it will be examined within future work.

9 METHODOLOGY

A Japanese tele-operated concrete finishing system was utilised as an example system. Cash flows for the machine include purchase, set-up, value of labour saving, value of material savings, energy costs, maintenance, on-site transfer costs, technicians pay, operators pay, transportation costs and the cost of repairs. Where objective data has not been available, subjective estimates have been applied.

The machine purchase cost was obtained from the manufacturer. In order to determine the effect the chosen input probability distribution had on the output criterion, five simulations were run using five different probability distributions. Simulation No.1 used subjective beta distributions, simulation No.2 used normal distributions with varied standard deviations, simulation No.3 used triangular distributions, simulation No.4 used skewed triangular distributions and simulation No.5 used uniform probability distributions. The difference between the results of each simulation were used to assess the overall implications of using the specified probability distributions functions to describe input cash flows.

10 RESULTS

The risk analyses produced negative mean values for each simulation (Table.2). The 95th percentile value for simulation No.1 is £39214.82, indicating that only 5% of the simulated net present values were above this figure. The second positive 95th percentile is for simulation No.3 (£14945.59), indicating that only 5% of the NPV iterations were above this figure. Simulation No.4 also returned a positive 95th percentile value of £3975.57. The 95th percentiles for simulation No.2 and No.5 are negative. The negative 95th percentile values are not acceptable in terms the net present value decision criterion.

Simulation's No.2, No.4 and No.5 indicate that there is a minimal probability that the investment project will yield positive returns. Normal output distributions are generated for simulations No.2 and No.3. Only normally distributed output probability density functions can be assessed in terms of their mean and standard deviation. The standard deviation of the returns about the mean values for simulations No.2 and No.3 are £5493.80 and £16210.29 respectively. Simulation's No.3 and No.4 indicate that there is evidently high risk associated with the proposed investment decision

The results presented for the chosen tele-operated machine indicate that there is an overall high level of down-side risk associated with the investment proposal. The authors conclude that the proposed utilisation of the example machine would not yield a beneficial financial advantage and that the financial risk associated with purchasing and utilising this system is too great for an investment decision maker to accept.

	SIM #1	SIM #2	SIM #3	SIM #4	SIM #5
Minimum	-81087	-32193.44	-65842.35	-69453.82	-70865.51
Maximum	97859.38	8107.307	37156.19	43630.37	13164.6
Mean	-13006.04	-11642.04	-11808.61	-26042.89	-30590.24
Std Deviation	29401.76	5493.805	16210.29	17082.54	15138.6
Variance	864463700	30181890	262773600	291813000	229177200
Skewness	0.3962016	-0.0045327	-0.0027058	0.3390736	0.0101338
Kurtosis	2.655643	2.961253	2.714861	2.777848	2.364121
Mode	-28529.42	-16263.39	-44283.05	-48646.02	-34836.05
10% Perc	-49731.66	-18706.79	-32980.5	-47403.37	-50758.7
20% Perc	-39703.71	-16239.43	-25865.76	-41176.66	-44565.16
30% Perc	-31201	-14477.65	-20659.32	-36265.74	-39456.59
40% Perc	-23452.91	-13052.59	-16064.8	-31809.53	-35080.39
50% Perc	-15706.84	-11656.16	-11902.74	-27358.66	-30450.82
60% Perc	-7676.908	-10275.08	-7530.655	-22686.26	-26009.64
65% Perc	-3052.801	-9535.626	-5316.346	-20130.03	-24051.3
70% Perc	1836.129	-8759.753	-2955.234	-17471.67	-21629.13
75% Perc	7114.313	-7943.96	-556.4946	-14494.53	-19225.99
80% Perc	12800.47	-6992.784	2128.483	-11088.58	-16742.95
85% Perc	19621.08	-5894.854	5534.925	-7432.872	-13990.25
90% Perc	27681.42	-4577.174	9603.88	-3021.423	-10551.19
95% Perc	39214.82	-2575.764	14945.59	3975.576	-5799.658

Table.2 NPV Simulation Results

11 DISCUSSION OF RESULTS

Experimentation with different methods of describing the input probability distributions has produced differences in the simulated performance criterion outcome. The results show that there is a substantial probability that the NPV will be negative. The resulting judgement based upon this result would signify a 'no-go' investment decision.

There is evidence to indicate that investment in this particular machine would yield a positive return as indicated by the positive percentiles. The probability of positive returns is minimal and, depending upon the risk aversion of the decision-maker, will not provide sufficient justification for the proposed investment.

More accurate cash flow data, regarding the input costs which have been subjectively estimated, may alter the simulation results. Historical data concerning the application of automated construction technology must be more readily available to construction industry financial executives and business development managers.

12 INTANGIBLE BENEFITS

Non-quantifiable benefits may be gained from the utilisation of automated construction systems. Those UK contractors that chose to invest in automated construction system may experience gains in terms of speed, productivity and quality. Reliability will form the basis for increased productivity. The use of advanced construction technology has the potential to improve a company's competitive advantage. The gaining of a competitive edge may assist in the strategic decision to invest in construction automation, which is initially dependent upon the level of incorporated financial risk.

Construction accidents, whether or not they involve an operative, will give rise to a cost and a consequence- the cost of the damage, delays caused by repair or repeat work as well as possible effects upon the quality and the performance of the finished product. Non-financial benefits associated with the introduction of construction automation may add to the cost-effective control of construction risks and add to the financial feasibility of construction automation investment.

12 CONCLUSION

Discrete results obtained from traditional NPV appraisal techniques may not adequately represent the inherent financial risk associated with construction automation investment. The over estimation of discount rates and the uncertainty surrounding cash flows may lead to automated construction systems being perceived as a impractical investment. Quantitative risk analysis does not replace managerial judgement. The decision to invest in construction automation can be examined more thoroughly by implementing probabilistic risk analysis techniques. The final go/no-go investment decision will ultimately rest upon the risk aversion of the corporate decision-maker.

Utilising subjective data to analyse the associated financial risk may successfully challenge the uncertainty surrounding the cash flows associated with construction mechatronics.

The resulting negative mean values for the risk analyses do not demonstrate the economic viability of the example system. The authors draw attention to the lack of historical cash flow data concerning the application of automated construction systems. To assist the introduction of robotic construction systems full-scale on-site demonstrations are required. The dissemination of realised cash flow data from on-site utilisation is essential for those wishing to investigate the economic feasibility of replacing traditional construction techniques with automated systems. The authors conclude that objective data, based upon historical usage or on-site field demonstrations, is essential for the accurate financial appraisal of automated construction systems. Accurate historical cash flow data is a necessity for the positive appraisal of automated construction systems.

Probabilistic risk analysis will assist in investigating the economic feasibility of automated construction systems. The decision to implement advanced construction technology will be a strategic decision made by construction firms that are committed to long term growth.

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