STRATEGIC MECHATRONICS INVESTMENT: UNDERSTANDING THE MANAGERIAL OPTIONS

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Real option pricing theory is emerging as a more effective and appropriate procedure for examining strategic investment, and in particular, construction mechatronics investment. On a net present value basis, high implementation costs, inappropriate discount rates and uncertain future cash flows may gauge automation investment as unpromising. The application of real option analysis combines capital budgeting and strategic planning within a decision framework. Waiting for new product information, new market information or competitors investment decisions are managerial options that are neglected within traditional discounted cash flow methodologies. The research examines the application of real option pricing theory to investment in imported automated construction technology. A preliminary investigation of the application of option pricing theory to the appraisal of construction mechatronics is presented. The derivation of pricing model parameters using historical market data is discussed. The research is ongoing and presently disputes the exclusive use of traditional investment appraisal techniques for the appraisal of construction mechatronics investment. The suggested methodology demonstrates the potential value of automated construction technology opportunities and may prevent short-termism within investment strategies through responding to varying market and industry circumstances.

Keyword: construction mechatronics, cash flow, pricing theory, real options, strategic investment.

INTRODUCTION

The application of "*now or never*" investment appraisal methodologies to strategic decisions concerning construction mechatronics investment does not include the timing and flexibility options available to construction management. Discounted cash flow (DCF) valuation strategies assume that the future is a predetermined chain of events and that the investment decision is immutable (Busby and Pitts 1997). Under investment is attributed to the misapplication and misinterpretation of DCF appraisal techniques (Drury and Tayles 1997). The misapplication of excessive discount rates diminishes the benefits associated with future cash flows. Automated construction technology exposes investors to risks previously not incorporated within the purchase of traditional construction plant and machinery. When utilizing DCF appraisal techniques, highly risk-averse decision-makers may subsequently overstate discount rates and generate an unfavourably investment decision.

Within financial markets, options are contractual arrangements bestowing the owner the right, but not the obligation, to buy or sell an equity or commodity at a given price

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at some distant point in the future. In return for the option, the purchaser pays a fee premium. The cost of the option depends upon the volatility of the underlying equity and the exercise price. There are two parties within an option contract, the buyer and the seller. The buyer has the right, but not the obligation, to exercise the option, whilst the seller receives the premium. One feature of an option is that, if the share price does not move as expected the option becomes worthless and the buyer has only lost the premium originally paid. The dynamics of the relationship between the value of a traded option, its time to expiration and the value of the underlying equity was captured within a partial differential equation developed by Black and Scholes (1973). The Black and Scholes model prices an option using five variables: share price (of underlying equity), option exercise price, risk free rate of interest, share price volatility and time.

Traditional option pricing theory can be applied to capital budgeting decisions in the form of real option pricing (Merton 1998; Amram and Kulatilaka 1999; Copeland and Antikarov 2001). Real option pricing theory (ROPT) facilitates improved understanding of investment decisions when compared to more conventional present value analysis (Scholes 1998). Corporate management may play an active role in achieving or exceeding the original estimated net present value of a project. Real options may be generated through mitigating losses or exploiting new capital investment opportunities. Emerging technologies may provide additional opportunities for growth and profitability. However, these may be impossible to describe or incorporate within traditional DCF analyses alone. The application of real option pricing theory to research and development expenditure was presented by Ho and Liu (2000). However, real option pricing theory has not yet been applied to the opportunity to invest in imported automated construction systems. The mapping of a construction mechatronics related investment as a pioneer venture (growth option) typically relates to an investment with a high initial expenditure and low prospective cash flows. Prudent mechatronics investment may initially allow an organization to prove automated construction technology, gain a positive track record and enhance their market position.

The application of real option pricing theory to the appraisal of imported automated construction plant and machinery is presented. A selection of currently available systems are evaluated and priced within the option space model developed by Luehrman (1998). ROPT may assist in the positive appraisal, strategic selection and implementation of automated construction technology.

METHODOLOGY

It is proving difficult to attract new recruits into the Japanese construction industry, owing to the perceived dangerous and hazardous nature of construction related activities. In order to counteract the severe labour shortages, the Japanese construction sector has privately funded the research, development and implementation of automated systems. The development and manufacturing of construction mechatronics may generate a surplus automated labour pool (Bennett, Flanagan and Norman 1987). These developed systems, rather than increasing unemployment, may be exported to international construction industries. Therefore, the purchase of automated systems for utilization within UK construction operations may assist the implementation mechatronics within the sector. However, the current techniques used to appraise investment within the UK construction sector appear to be inappropriate for construction mechatronics appraisal.

Recent research indicated that the UK construction sector used qualitative techniques individually, more than quantitative (Akintoye and MacLeod 1997; Baker, Ponniah and Smith 1998). It was reported that the use of a combination of both qualitative and quantitative decision analyses was extensive. The use of real option pricing theory was not surveyed, therefore its widespread use within the UK construction sector is questionable.

A mechatronics investment opportunity may be equated to a call option. The plant hire firm or contractor has the right, but not the obligation, to acquire the new item of plant or machinery. Recognizing that a mechatronics investment decision is similar to a call option will assist decision-maker in understanding the crucial role of uncertainty within their decision methodology (Dixit and Pindyck 1995). If a similar option was available within the UK financial markets as a traded option then it could indicate the possible value of the real option. However, due to the uniqueness of the investment opportunity and the unavailability of a traded option with similar characteristics, a suitable option must be constructed.

Having examined the current developments within the field of automated construction technology, the authors have selected a sample of plant and machinery which is either currently available to purchase or hire from Japanese and Swedish machine manufacturers or under development. Owing to construction contractors minimizing fixed capital through subcontracting labour and hiring plant and machinery, it is assumed throughout the developed appraisal methodology that automated technology will be introduced in conjunction with the UK plant hire sector. Therefore, construction contractors could utilize available technology without intensifying their fixed capital investment.

Utilizing the methodology described by Harris and McCaffer (1995), marginal hire rates (MHR) were calculated and a hire rate premium was added to determine the cash flows generated over the economic life of the selected machines. The adapted Harris and McCaffer model is as follows:

$$\mathrm{MHR} = \frac{O_{wn} + O_p}{h} \qquad \text{(Equation 1)}$$

Where:

$O_{wn} = I + L + Depreciation + Interest$ and $O_p = F + O + R$

The variables within O_{wn} and O_p are as follows:

I =Insurance
L =Licence and tax
F =Fuel
O =Oil and grease
R =Repairs and maintenance
h =Hours utilized (annual)

Using Equation.1, a premium (50%) is then added as follows:

$$\mathrm{HR}_{+\mathrm{premium}} = \left(\frac{O_{wn} + O_p}{h}\right) \times 1.50 \qquad \text{(Equation 2)}$$

The annual cash flows for the determination of the NPV of the future cash flows are calculated using Equation 3. The final year cash flow is calculated by adding the resale value to the cash flow derived from Equation 3.

$$CashFlow = \left(h \times HR_{+premium}\right) - \left(O_{wn} + O_{p}\right) \qquad \text{(Equation 3)}$$

Table 1 presents a summary of the calculations. The methodology assumes that repair; maintenance and other associated costs are calculated as a percentage of the purchase cost of the machines. Purchase costs were obtained from machine manufacturers where available. Manufacturing costs were adopted as purchase costs for the ABCS and Big Canopy systems. These systems are currently only advanced prototypes, but they will inevitably be exported further to development and more intense application within their domestic sector. Having incorporated corporate taxation and capital allowances for plant and machinery, NPVs for future cash flows are calculated using Equation 3. The discount rate for the NPV calculations is determined from the weighted-average cost of capital (WACC) for a theoretical investing plant hire organization. The cost of equity capital has been calculated utilizing the capital asset pricing model and the cost of debt capital by adopting the yield to maturity on long dated treasury stock (Drury and Tayles 1997). The WACC is an acceptable approximation as long as the project does not differ greatly from other company projects in terms of its specific risk (Dixit and Pindyck 1995). Construction mechatronics investment presents new technological and market risks. However, specific risk will be favourably altered due to the tangible and intangible benefits of implementing appropriately feasible construction mechatronics.

Table 1: Calculation of marginal plant hire rates

	Robocon	**BM330**	**Excavator**	**Big Canopy**	**ABCS**
Inititial Cost (£)	3500	10000	80000	5000000	10000000
Resale Value (£)	350	1000	8000	500000	1000000
Average Working Hours (h)	2000	2000	2000	2000	2000
Economic Life (Years)	5	5	5	20	20
Insurance Premiums (5%)	175	500	4000	250000	500000
Licences and Tax (2.5%)	88	250	2000	125000	250000
Fuel (2l, 5l, 10l, 200l,250l/hr)	400	1000	2000	40000	50000
Oil and Grease (10% of fuel)	40	100	200	4000	5000
Repairs (5,10,15 & 20%)	175	1000	12000	750000	1000000
WACC	0.15	0.15	0.15	0.15	0.15
Depreciation	630	1800	14400	225000	450000
Interest (A/P, i%, n)	0.2983	0.2983	0.2983	0.1598	0.1598
Interest on finance	1044.10	2983.16	23865.24	798807.35	1597614.70
Ownership Cost (O_{wn})	1936.60	5533.16	44265.24	1398807.35	2797614.70
Operating Cost (O_p)	615	2100	14200	794000	1055000
MHC (£/hour)	1.28	3.82	29.23	1096.40	1926.31
$HC_{premium}$ (£/hour, +50%)	1.91	5.72	43.85	1644.61	2889.46

Straight line depreciation is assumed within the calculations for the marginal hire rates. The cost of financing the capital expenditure is determined by calculating the annual uniform series payments that extend for the economic life of the purchased system. The uniform series capital recovery factor (Pilcher 1992) is determined as follows:

$$A = P\left[\frac{i(1+i)^{n}}{(1+i)^{n} - 1}\right] \qquad \text{(Equation 4)}$$

where *A* is the uniform series end-of-period payment, *P* is the principle (a sum of money invested in the initial year), *i* is the interest rate per unit time expressed as a decimal (WACC) and n is the economic life of system.

Further to calculating the NPV for each system, the properties of the proposed investment are equated to the five variables that determine the value of a simple call option on a traded equity. The market value of a call option is determined from the following five variables:

S = the current stock price
X = the future exercise price
R_f = the risk free rate of return (YTM 3-mnth Treasury Bills)
t = the time to expiration
σ = the volatility of stock returns

The Black and Scholes option pricing formula may then be utilized to determine the value of the option. Alternatively, a model developed by Luehrman (1998) may be applied and an option may be positioned within an option space diagram. The Luehrman model assumes that an investments project option value and its NPV are equal when the investment can no longer be deferred, that is when the option has reached its date of expiration. Within the model, the possibility of deferring the investment gives rise to two sources of additional value. Firstly, the value of the interest or time value of money accrued on the money not consumed. Secondly, the market or sector within which the provisional investor is operating within may change. Traditional discounted cash flow analyses do not include this possibility. Real option valuation incorporates the value of managerial patience and includes the possibility of active investment management. The five option value variables outlined previously are used to calculate two option value metrics, the value to cost metric (NPVq) and the cumulative volatility metric ($\sigma\sqrt{t}$).

The Luehrman metrics are calculated as follows:

$$\text{Value to Cost} = \frac{S}{PV(X)} \qquad \text{(Equation 5)}$$

$$\text{Volatility} = \sigma.\sqrt{t} \qquad \text{(Equation 6)}$$

Where:

$$PV(X) = \frac{X}{(1+r_f)^t} \text{ and } S = NPV + X$$

To eliminate any negative values, the difference between the present value of the future cash flows and the present value of the exercise price is expressed as a quotient. Having calculated the Luehrman model metrics, the proposed investment may be positioned within a two-dimensional option space diagram (Figure 1). As the value of the call option increases, its position moves horizontally, diagonally or vertically from the origin of the option space diagram.

Therefore, having estimated future cash flows and calculated the value to cost and volatility metrics, the proposed investments may by positioned within the option space diagram. Once positioned within the option space diagram, it will be evident whether or not the proposed investment option should be exercised. Furthermore, if the real option is currently “*out of the money*”, what may be needed to cause the investment to become “*in the money*” may be displayed. Methods of measuring and estimating volatility are investigated and recommendations for data acquisition are presented. The issues related to subjective cash flow estimation are discussed. Future areas of research are outlined with recommendations for obtaining objective data for use within real-option valuation methodologies.

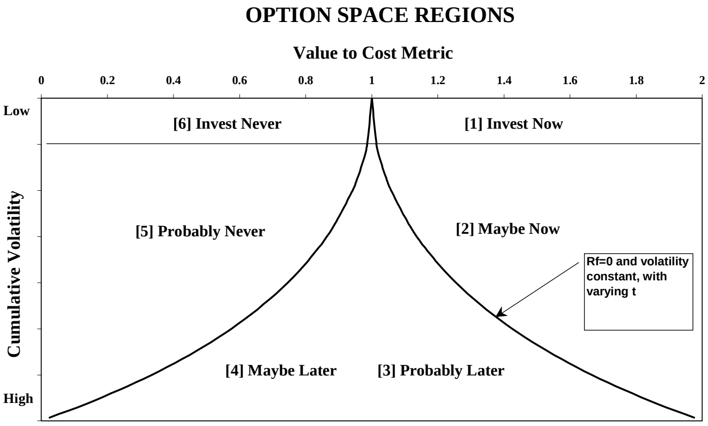

Figure 1: Option space regions (Luehrman 1998)

ALTERNATIVE SOLUTION METHODS

Alternatives to the analytical solution described within the methodology are outlined within Figure 2.

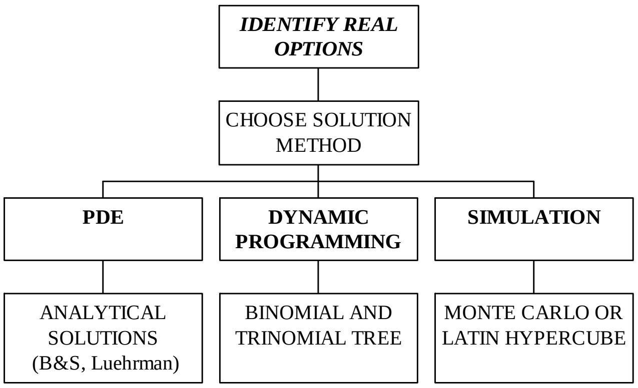

Figure.2: Solution techniques

The presented results utilize the analytical solution outlined by Luehrman (1998). Future work will examine the use of dynamic programming and stochastic simulation to compare the available techniques for option valuation and their relevance to mechatronics real option valuations. Dynamic programming lays out all future possible outcomes and folds back from the optimal future strategy to determine the value of the real option. Stochastic simulation may be utilized to provide a probability distribution for the optimal strategy at the decision date for thousands of possible future outcomes. The solution method utilized within the current work is the analytical solution outlined by Luehrman (1998).

CALCULATING HISTORICAL VOLATILITY

A stock price is discontinuous and sporadic. Market prices fluctuate around one stable level, with the occasional shocks that send them either soaring or into free fall. The greater the volatility of a stock, the more likely that the exercise price will be exceeded by the stock price and the value of the option will increase.

Historical volatility is the statistical measure of past price movements. Historical volatility estimates are based on recently observed market value fluctuations. For the purpose of construction mechatronics investment analysis, historical volatility may be estimated by calculating the volatility of the FTSE construction and building materials index over a time period equal to the time to expiration of the real option.

Utilizing the methodology outlined by Amran and Kulatilaka (1999), historical volatility has been calculated over a five-year period (1995 to 2000). A sample from the historical volatility calculations is presented in Table 2. The continuously compounded return is calculated as:

$$u_t = \ln\left(\frac{A_t}{A_{t-1}}\right) \qquad \text{(Equation 7)}$$

where u_t is the return between *t-1* and *t*, and A_t is the asset value at time *t*. Historical volatility is then calculated using the expression for calculating standard deviations:

$$\sigma = \sqrt{\frac{\Sigma\left(u_t - \bar{u}\right)^2}{(n-1)}} \qquad \text{(Equation 8)}$$

where $\bar{u}$ is the mean of the price ratio calculated in column two of Table 2. The historical time-period used to estimate volatility must be no less than the time to expiration of the real option. This will therefore capture the infrequent movements in the underlying asset (surrogate market index). Table 2 represents a sample of the table used to calculate historical volatility over a period of 60 months.

Table 2: Calculation of historical volatility

Date	$\frac{A_t}{(A_t - 1)}$	$\ln\frac{A_t}{(A_t - 1)}$	Monthly Return (%)
31/1/1996	1.0262	0.0259	2.6215
29/2/1996	1.0212	0.0210	2.1176
30/11/2000	1.0286	0.0282	2.8614
18/12/2000	1.0234	0.0231	2.3352
		Monthly Volatility (%)	0.14
		Annual Volatility (%)	0.48

DISCUSSION OF PRELIMINARY RESULTS

The results of the real option analyses applied to the five selected automated construction systems are presented within Table 3.

Both the Robocon and BM330 systems have time to expiration of zero. These systems are currently available to purchase and have been successfully utilized on Japanese and UK construction projects. Therefore, both systems are positioned within area No.1 ("*invest now*") of the option space diagram (Figure 3). According to the real option analysis presented, investment should be undertaken as soon as possible. It may be observed that the more advanced and initially expensive systems are within the area which indicates that the option should be exercised "*maybe later*" (No.4,

Figure 1). Owing to the tele-operated excavation system being only an advanced prototype and not yet being manufactured for sale, its real option time to expiration is assumed to be five years. This pertains to a cumulative volatility metric of 1.07. The value to cost metric is greater than 1.0 (1.42), which indicates that the system could be a profitable investment depending upon how the application of these systems prevail within the UK construction sector. The Big Canopy and ABCS systems are highly sophisticated automated high-rise construction systems, which may take some time to be implemented within the UK construction sector. Therefore, their real option time to expiration is ten and fifteen years respectively. Again, these systems fall within option space region No.4, and appear to be profitable future investments. The development and implementation of these systems should be monitored with the aim of exercising the investment option when the UK construction market conditions are favourable.

Table 1: Summary of Luehrman model values

Variable	Robocon	BM330	Excavation	Big Canopy	ABCS
S	3818.19	11311.39	87440.63	5370276.41	10659902.10
X	3500	10000	80000	5000000	10000000
t	0	0	5	10	10
R_f	0.06	0.06	0.06	0.06	0.0583
σ	0.48	0.48	0.48	0.48	0.48
$PV(X) = X / (1+R_f)^2$	3500	10000	60262.34	2837148.34	5674296.68
NPVq = S / PV(X)	1.09	1.13	1.45	1.89	1.88
$\sigma\sqrt{t}$	0	0	1.07	1.52	1.52

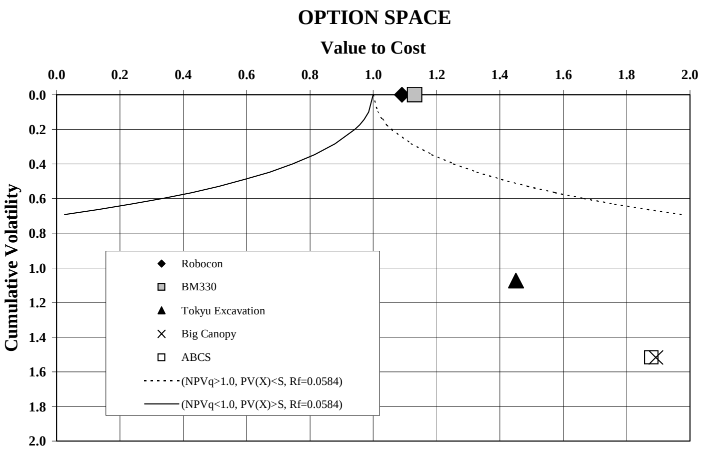

Figure 3: Option space diagram

CONCLUSIONS

Real option pricing theory has the potential to assist construction engineering related strategic decision analysis in a variety of forms. A timing option was presented as a form of pioneer venture relating to the decision of a plant hire firm to invest in imported automated construction technology.

Future work will examine the sensitivity of the option values to the input parameters (the “Greeks”), the cross-sectional correlation among input variables, the use of Monte Carlo simulation to assess project volatility and the development of specific sample strategy space diagram for construction automation investment. The authors also propose to frame construction mechatronics investment opportunities as learning, switching, rainbow, operation, compound (growth) and abandonment real options. Analysing the possible flexibility options will assist the UK construction sector in understanding the value of the available technology and the ROPT appraisal methodology.

The application of ROPT to the strategic appraisal of automated plant and machinery is challenged by the practical implementation obstacles (technology and operating risk) and the subjective nature of the associated model input parameters (input cost and model risk).

Successfully implemented automated construction technology consists of a range of tele-operated single-task systems, which have been manufactured and engaged in construction project operations. Technical specifications and maintenance cost data is available, although the cost of repairs and maintenance will be dependent upon the multiple sources of operating uncertainty. Operating and ownership cost uncertainty may stem from inappropriate utilization, unpredictable site conditions and inept operation. Many single-task systems have not been compared scientifically to traditional construction operations. Often, the systems pre-empt traditional construction activities due to dramatically increasing safety or productivity.

The majority of systems are currently advanced prototypes that require further field development before they will be manufactured. Within the current developmental stage of construction automation, it is difficult to attain absolute estimations of operating costs and potential tangible benefits. Cost information may also be sensitive to the competitiveness of the construction companies and machine manufacturers that are developing the systems. However, manufacturing costs or projected purchase costs may be utilized in conjunction with the existing maintenance cost models to predict future cash flows.

Technology and operation based uncertainties may be summarized as follows:

- Labour force actively objecting to new technology (Luddism)
- Unexpected site conditions
- Unexpected technological difficulties
- Operation and maintenance training requirements
- Contingency plans for alternative to automated operations (stand-by labour force)
- Favourable labour market conditions
- Total hours utilized

ROPT model implementation problems may be summarized as follows:

- Subjective cost estimates are required to estimate the static value of the investment
- Investment volatility is based upon subjective cash flow data
- Difficulties associated with quantifying intangible benefits of the machines
- Time to expiration of prototype systems is subjective

In conjunction with traditional DCF analyses, ROPT adds financial insight into the examination of strategic investment possibilities. ROPT has the benefit of incorporating the value of decision timing and flexibility within strategic investment decision analyses. The presented methodology does not replace the need for strategic judgement, but may assist strategic decision making within construction related organizations. Furthermore, the benefits of construction mechatronics investment may appear to be more favourable when appraised using ROPT.

REFERENCES

Akintoye, A.S. and MacLeod, M. J. (1997) Risk analysis and management in construction. *International Journal of Project Management*. **15**(1): 31-38.

Amram, M. and Kulatilaka, N. (1999) *Real Options: Managing Strategic Investment in an Uncertain World*. Boston, USA: Harvard Business School Press.

Baker, S., Ponniah, D. and Smith, S. (1998) Techniques for the analysis of risks in major projects. *Journal of the Operational Research Society*. **49**: 567-572.

Bennett, J., Flanagan, R. and Norman, G. (1987) *Capital and Counties Report: Japanese Construction Industry*. Centre for Strategic Studies, University of Reading, May.

Black, S. and Scholes, M. (1973) The pricing of Options and Corporate Liabilities. *Journal of Political Economy*. **18**: 637-654.

Busby, J.S. and Pitts, C.G.C. (1997) Real Options and Capital Investment Decisions. *Management Accounting (British)*. **75**(10): 38-40

Copeland, T. and Antikarov, V. (2001) *Real Options: a practitioner's guide.* London: Texere Publiching Limited.

Dixit, A.K. and Pindyck, R.S. (1995) The Options Approach to Capital Investment. *Harvard Business Review*. (May/June): 105-115.

Drury, C. and Tayles, M. (1997) The misapplication of capital investment appraisal techniques. *Management Decision*. **35**(2): 86-93.

Harris, F. and McCaffer, R. (1995) *Modern Construction Management (4th Edition).* London: Blackwell Science.

Ho, S. and Liu, L.Y. (2000) Valuation and Strategies for Investment on Automation and Robotics. *Proceedings of the 17th International Symposium on Automation and Robotics in Construction*. Taipei, Taiwan, (Sept 18th-20th): 381-386.

Luehrman, T.A. (1998) Strategy as a Portfolio of Real Options. *Harvard Business Review*. **76**(5): 89-99.

Merton, R.C. (1998) Applications of Option Pricing Theory: Twenty-Five Years Later. *The American Economic Review,* **88**(3): 323-349.

Pilcher, R. (1992) *Principles of Construction Management (3rd Edition).* London: McGraw-Hill.

Scholes, M.S. (1998) Derivatives in a Dynamic Environment. *American Economic Review,* **88**(3): 350-370.