VALUATION AND STRATEGIES FOR INVESTMENTS ON AUTOMATION AND ROBOTICS

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Abstract: This paper presents a quantitative valuation method for automation/robotics investments based on modern option pricing theory in finance. This framework explicitly considers the investments' uncertainty/risk and embedded managerial options. It further aligns the valuation of the investments with the market opinions. The analysis may help construction firms more accurately compute the value of automation/robotics investments, and provide useful strategies with respect to various automation/robotics investments.

Keywords: Automation investment, robotics investment, valuation, option pricing theory, real options, capital budgeting, investment timing, risk management, strategic investment.

1. INTRODUCTION

Automation and robotics are recognized as part of the solutions to improve construction productivity, safety and skilled labor shortages, and to reduce costs. By achieving these improvements, a construction firm could obtain not only direct cost savings but also competitive advantages that are vital to the firm's future growth.

However, automation/robotics development and applications typically involve large capital investments. In many cases, it seems difficult to justify the automation and robotics investments [1]. Warszawski and Navon [1] pointed out some serious problems of robotics investment evaluation in the construction industry. Moreover, except for those near-matured/matured applications of automation/ robotics, most investments are characterized by the uncertainty of actual cost and benefit of the early-stage automation and robotics developments, especially when the development involves research and development (R&D) activities. Managers may easily forego some risky and low immediate return but highly valuable investments. As a great benefit to the business, managers need a better discipline or methodology in the valuation and decision making process for the automation/robotics investments.

Traditional costs/benefits and capital budgeting analyses such as "Net Present Value" (NPV) tend to ignore an investment's *strategic* value and help little in evaluating complex investment decisions. Managers would like to know when is the right time to invest, now or later. Should they invest in automation/robotics projects that might have "negative" NPV but could possibly create valuable competitive advantages later? What is the value of the investment opportunity?

2. OPTION PRICING THEORY

Option pricing theory recognizes the interactions among option holder's optimizing behaviors, asset's uncertainty, and market disciplines. Recently, the option pricing theory is often applied in the evaluation of non-financial assets or *real* investments. Researchers sometimes named it "real options". This dynamic pricing process overcomes difficulties in "discounting approach", and successfully computes the value of an investment more realistically. We argue that modern option pricing theory can be very suitable for the study of automation/robotics investments.

A "European call option" is a type of contract giving the right to buy a specific asset, such as a common stock, at a specific price on a specific date in the future. An example could be a 3 month IBM stock call option. If today is Sept. 20th, this call option may specify that the option issuer gives the holder the right to buy an IBM stock from option issuer at the exercise price $120 on the maturity date, Dec. 20th. Therefore, on Dec. 20th the option holder must decide whether to buy an IBM stock at $120 or not. If the the stock price of IBM is greater than $120 on Dec. 20th, say, $150, the option holder will certainly "exercise"

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his option, that is, to buy an IBM stock and make \$30 profit. If the stock price is \$110, the option holder will just abandon his option and make \$0 profit. The question is: how to set a price for this stock option.

Another type of option is called "American call option". The American style option allows the holder to exercise the option *before* its maturity date. Therefore, an American call option on IBM allows the holder to buy an IBM stock at \$120 on any day before Dec. 20th. It can be proved that under certain conditions even when the stock price rises above \$120, it may not be optimal to exercise the option immediately. For example, if on Sept. 20th, the stock price is \$121, it is not optimal to exercise the option immediately and earn only \$1 profit. The holder should wait and keep the option alive. It turns out that the problem of *when* to optimally exercise an American option has to be solved simultaneously with the *price* of option.

Since Black and Scholes' [2] breakthrough in the valuation of stock options, theories regarding *asset valuation* concept and process has advanced into a new era. The most powerful feature in their pricing approach is that the price can be solved independent of individual investor's risk attitude. After Black and Scholes, Cox et al. [3] developed an equivalent but more intuitive approach in pricing options.

3. SINGLE-STAGE INVESTMENTS: OPTION TO WAIT AND INVEST

A single-stage investment involves only *one* major investment outlay, and the project is completed soon after the capital is committed. Examples in automation/robotics investments could be the purchase of a *near-matured*/*matured* technology or equipment such as a fully automated rebar CAD/CAM system.

3.1 The analogy to American options

Typical capital budgeting tools evaluate a project by computing its NPV (Net Present Value) on the "Invest now or Never" basis. However, it can be shown that, under uncertainty, to invest immediately may not be the best strategy even when the NPV is positive. Management has the *option to "wait and see*", that is, to let the uncertainty unfold and make decisions according to the updated information. In an open market with many technology developers such as U.S., this decision for investing in automation/ robotics is similar to the decision for exercising an American option. This American option feature can be named as *timing option* and it is the most important *managerial option* embedded in a single-stage investment.

For example, suppose that an investment requires a fixed cost of \$20 millions(m), and the management can make investment on any day before Dec. 20th. If today, Sept. 20th, the management's estimate on the expected benefit is \$21m, then, the management's questions are: to invest today or to wait/delay, and how to compute the value of the investment opportunity. The investment problem here is analogous to an American option. It needs a fixed cost of \$20m to invest/exercise. The benefit will be \$21m, should the option be exercised today. Alternatively, management can *delay* the decision, while the expected benefit is uncertain in the future. Note that the expected benefit is *uncertain/risky* due to the uncertain future market conditions. As a result, the optimal investment timing and the value of the investment opportunity can be solved by American option pricing theory.

3.2 Valuation of European and American options, and the single-stage investments

We shall use Cox et al.'s approach [3] to show some general ideas of solving option value and how the single-stage investment problem is related with American options. The basic idea to solve a price that is consistent with capital market is the economics' "no arbitrage opportunity" argument. That is, if the asset is mis-priced, the arbitrage transactions will adjust the prices until the market equilibrium is reached and there exists no arbitrage opportunity.

Cox et al.'s approach is also called the "binomial approach". Given a specific distribution of the asset price in the future, one can transform the distribution into a binomial tree as shown in fig. 1, which represents random prices' possible future realizations. V is the stock price or expected benefit. For illustration, we only divided the 3 months into 3 periods. After each period, the stock price can either go up by certain percentage, u, for example, 120%, or go down by d=1/u=1/(120%) =83.3% with the probability q and 1-q, respectively, corresponding to the asset's distribution and the "no arbitrage opportunity" requirement. Typically, the binomial approach assumes that the values for q's in each time step are constant. Here V_{uud} represents that V goes up at month 1 and 2, and down at month 3.

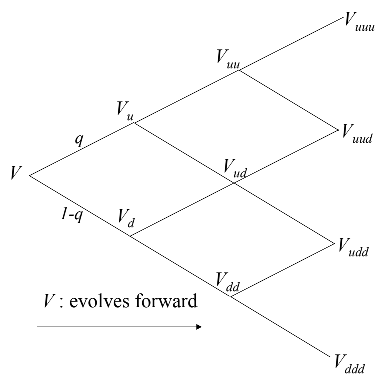

Figure 1. The Binomial Tree of V's Distribution

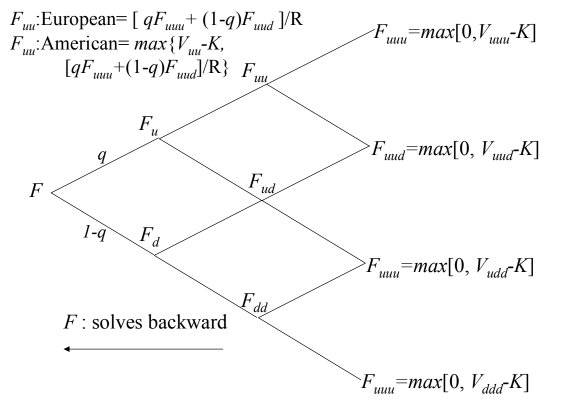

Figure 2. Binomial Tree for Solving Option Value

In calculating European options, we need to perform the calculation as shown in Fig. 2, where F is value of the option or investment opportunity. Fig. 2 shows that we solve the option price backward recursively from the maturity date. First, the option price is $\max[0, V-K]$ at maturity, where K is the exercise price or investment cost. At month 2, the option value at each node is obtained by computing the discounted expected month 3 option value. For example, $F_{uu} = \frac{1}{R}[qF_{uuu} + (1-q)F_{uud}]$, where R is the discounting factor. Solving backward recursively, F can be obtained.

Nevertheless, our single-stage investment problem is similar to American options. In American options, one needs to perform the calculation shown in Fig. 2 as well. The month 3 calculation is the same as European. However, the month 2 calculation involves the *comparison* between the discounted month 3 option price's expectation and the early exercise profit at month 2. If the early exercise profit V_{month2}-K is greater than F_{month2}, then one should *exercise/invest* at month 2, otherwise, one should keep the option alive and *wait* until month 3. For instance, as shown in Fig. 2, the option price when $V = V_{uu}$ is $F_{uu} = \max\left[V_{uu} - K, \frac{1}{R}[qF_{uuu} + (1-q)F_{uud}]\right]$. This is so called optimal stopping decision in stochastic dynamic programming. The tree in Fig. 2 for American options becomes a *decision and valuation tree*. Fig. 3 shows the option price curve of an American option with exercise price, \$120. The 45^o slope dashed line is the payoff function at maturity or upon exercise, $\max[0, V-K]$. V^* is the price when the early exercise is optimal, in other words, for any $V < V^*$, one should not exercise the option or make the investment immediately.

3.3 Investment timing and valuation framework

Taking the analogy between the American call options and automation investments, we may develop

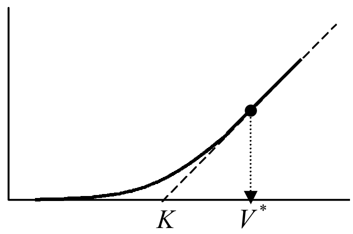

Figure 3. The American Option Value Curve

a methodology of evaluating a single-stage automation/robotics investment.

Step 1: Assume the typical setup in literatures regarding the uncertainty of project value, V, that V follows a geometric Brownian motion, a continuous-time stochastic process. The dynamics of the investment payoff V is of the form:

$$\frac{dV_t}{V_t} = \mu_V dt + \sigma_V dw_V \qquad (1)$$

where V_t is the present value of the expected cash flows resulting from an investment project if the project is completed at *t*, μ_V is the instantaneous expected rate of return/growth rate of V_t, σ_V is the instantaneous standard deviation of the project's growth rate, and dw_V is the random increment to the Wiener process[1], w_V. Note that μ_V and σ_V are also known as the asset's *drift* and *volatility*, respectively, and they are assumed to be constant over time. μ_V and σ_V may come from an expert's assessment based on available market information. Equation (1) implies: $\ln\frac{V_{t'}}{V_t} = \ln V_{t'} - \ln V_t \sim N[(\mu_V - \frac{\sigma_V^2}{2})(t'-t), \sigma_V^2(t'-t)]$, where $t' > t$. This shows that $\ln V_{t'}$ is normally distributed so that $V_{t'}$ has a lognormal distribution as shown in Fig. 1. It is widely recognized that the price distributions of most stocks are actually quite close to lognormal [5]. This distribution has also been broadly adopted by both researchers and practitioners in the modeling of *risky physical asset prices* such as an oil reserve, a start-up venture, and an investment project. In a single-stage investment, we shall assume that the automation investment's cost, *K*, is constant.

Step 2: Align the dynamics of V in equation (1) with the market opinions. This is a critical step in option pricing especially when the underlying asset, V, is not a traded security. Suppose that there exists a similar-risk traded financial asset, say, a stock, that has the same risk term $\sigma_V dw_V$. According to Merton [6], a market equilibrium rate of return, μ_{VS} can be determined corresponding to its risk. Equation (1) is the dynamics of an un-finished project. As a result, usually μ_V (of non-traded assets) will be lower than μ_{VS} (of traded assets) and their difference is:

[1] Wiener process' increment, dw_V, is normally distributed with a mean of 0 and a variance of *dt*. See Dixit and Pindyck, p.63 [4].

$$\delta_V = \mu_{VS} - \mu_V \quad (2)$$

where δ_V is called the *rate of return shortfall* of a non-traded or un-finished project. The detailed discussion of equation (2) is beyond our scope. In short, in an automation investment, δ_V is determined by capital market's *observable* opinions, μ_{VS}, and the characteristics of the investment, μ_V. In some cases, μ_V can be inferred by analyzing the *competition* from competitors. For example, if many competing firms are expected to make the same automation investment in the near future, then the benefits from the investment will *shrink* due to the delaying of the investment. In this case, μ_V might be a *negative* rate.

Step 3: Compute the value of the investment that contains timing option. Cox et al.'s binomial approach can be used to obtain solutions. However, Since McDonald and Siegel [7] showed that the value of a *perpetual* American option could be solved analytically, we shall adopt their analytical solutions for clarity and the ease of sensitivity analysis. Note that a perpetual option is an option that will never expire. By fixing the investment cost *K*, McDonald and Siegel's [7] solution can be reorganized to value a single-stage automation/robotics investment:

$$F(V;K) = (V^* - K)\left(\frac{V}{V^*}\right)^\beta \quad \text{when } V \le V^* \quad (3)$$

$$F(V;K) = V - K \quad \text{when } V > V^*$$

where *F* is the value of the investment opportunity,

$$V^* = K\left(\frac{\beta}{\beta - 1}\right), \quad (4)$$

$$\beta \equiv \left(\frac{1}{2} - \frac{r-\delta_V}{\sigma_V^2}\right) + \sqrt{\left(\frac{r-\delta_V}{\sigma_V^2} - \frac{1}{2}\right)^2 + 2r/\sigma_V^2} \quad (5)$$

Equation (4) can also be rewritten as

$$C^* = \frac{V^*}{K} = \frac{\beta}{\beta - 1} \quad (6)$$

Here C^* is the critical ratio of V^* to *K* such that the investment should be undertaken without waiting. V^* is the *investment threshold*. Note that from equation (3)-(5), we know that although the investment is risky, the value of the investment opportunity does *not* depend on any parameters determined by the investor's risk attitude. In an efficient capital market, the investors as the stockholders (owners) of the company will compel company's management's investment valuation to be consistent with above market disciplines.

3.4 An illustrative example

SmartCom Inc. specializes in hazardous material processing/removing. The management is evaluating the purchase of a newly developed robot that can improve the material handling efficiency by 20%. The robotics investment needs \$1 million (*m*). SmartCom estimates that the productivity improvement can increase the number of yearly winning bids by certain percentage for certain years in the future. Suppose that the present value of these estimated benefits in the future is \$1.1*m* according to current market conditions. Should SmartCom invest right away or delay?

The investment has \$0.1*m* NPV. According to conventional capital budgeting SmartCom should invest right away. We now consider the option to delay/wait. To perform the analysis according the 3 steps above, we need to model the risk and estimate the parameters in the framework. Suppose that these estimates are: $\mu_V = 0$, $\sigma_V = 0.25$, $\mu_{VS} = 0.12$, $\delta_V = \mu_{VS}$ - 0 = 0.12 by equation (2), and *r*=0.05. Note that σ_V =0.25 is estimated from the volatility of several hazardous material handling firms' stock prices because of their similar risks with SmartCom. Computing (5) and (6), we obtain C^*=1.37, that is, $V^* = 1.37K = \$1.37m$. Thus SmartCom should *delay* the investment until the expected future benefit reaches \$1.37*m*. The value of the investment opportunity when *V*=\$1.1*m* is \$0.17*m* instead of \$0.1*m*. Therefore, the timing option's value is \$0.07*m*. Fig. 4 shows the value of the investment opportunities with respect to different σ_V. The solid line curve represents our base case. The short-dashed line shows when *V* is *less volatile* with σ_V=0.15 and μ_{VS}=0.08, SmartCom should invest earlier when *V* reaches \$1.28*m*. The long-dashed line shows that if the hazardous material business is *highly volatile* with σ_V=0.4 and μ_{VS}=0.18, SmartCom should wait until *V* reaches \$1.54*m* to justify an immediate investment. Fig. 4 also shows that, surprisingly, higher risk, σ_V, will induce higher value of investment opportunity.

Suppose that SmartCom is facing strong competitions in the market such that the benefits from the robotics investment will *shrink* by 30% per year due to the possibility of his competitors' investing in the same robot. Here we call this competition as the "*investment competition*". In this case, we may

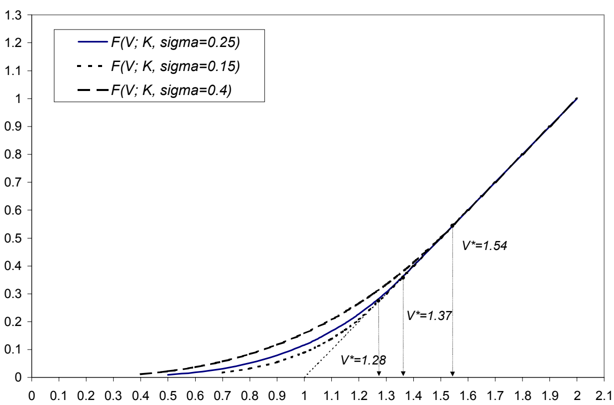

Figure 4. The Investment Timing and Value of the Investment Opportunity w.r.t Various Volatilities

estimate μ_V = -0.3 due to the market shrinkage. Consequently, $\delta_V = \mu_{VS} - \mu_V = 0.42$. The analysis shows that SmartCom should commit the investment as soon as V reaches \$1.08*m* instead of waiting. However, if the competition is not very intensive, say, μ_V = -0.1, SmartCom should wait until V reaches \$1.17*m*. Our base case, μ_V = 0, could be the case that SmartCom faces no competition or owns the patent to the robot technology.

3.5 Single-stage investment strategies

Compared to conventional "invest when the *NPV* is positive" rule, our option pricing theory based methodology provides a richer investment strategy profile. For example, with higher volatility of V and lesser investment competition, the management should make the investment with higher threshold, and vice versa. Our analysis also explains why sometimes management hesitates to invest in automation/robotics even when the project has shown positive *NPV*. Low investment competition and risky business environment in construction industry contribute to the delay of the investments. Note that to delay an investment is by no means to abandon an investment; therefore, the management should keep *monitoring* those investment opportunities that have positive *NPVs*.

4. MULTI-STAGE INVESTMENTS: OPTION TO STOP OR CONTINUE

A multi-stage investment has at least two stages of investments and each stage has one major investment outlet. Many automation/robotics investments are of this type. Examples include the investments that involve several years of R&D activities and, if successful, will create opportunities to broaden the firm's business/territory.

4.1 Option to stop or continue

One of the most important managerial options embedded in a multi-staged automation/robotics investment is the option to quit or continue after each stage. In other words, management can decide not to invest further in next stage, if either the outcome from previous phase or the market situation turns out to be disadvantageous. In conventional capital budgeting, decision makers discount and sum up the expected cost incurred in each phase, and compare it with the present value of expected future payoff. The option to stop/continue is therefore ignored in the valuation process. Even one tries to use decision tree-like technique to consider the option, it is hard to determine an appropriate discount rate in the changing risk profiles. Option pricing theory can be used to account for the managerial options and align the value of investment with capital market. For simplicity, here we shall demonstrate the valuation and investment strategies of a *two-stage* investment without considering its timing option, although more complex models can be developed based on the same set of principles.

4.2 Two-stage investment valuation framework

Suppose that an automation/robotics technology is still at the R&D stage, the investment requires K_1 initial investment outlay, and it will take τ years to complete these activities. At year $\tau+1$, the second stage, the company will start applying the technology. Suppose the expected investment in the second stage is K_2 and the expected payoff from the automation/ robotics application is $V_{\tau+1}$. At year $\tau+1$, the investment will be continued if $V_{\tau+1} \geq K_2$, and will be stopped if $V_{\tau+1} < K_2$. As a result, the payoff function at $\tau+1$ is $max[0,\ V_{\tau+1} - K_2]$. Again, we assume that V follows a geometric Brownian motion as shown in equation (1). If K_2 is a constant, then the value of the option to invest in the second stage is the value of a European call option. For simplicity, we shall assume K_2 is fixed. McDonald and Siegel's [8] analytical solution can be rearranged to obtain the option value:

$$F(V, K_2, \tau) = Ve^{-\delta_V \tau} N_1(d_1(\frac{V}{K_2}e^{-\delta\tau})) - K_2 e^{-r\tau} N_1(d_2(\frac{V}{K_2}e^{-\delta\tau})) \tag{7}$$

where $N_1(d) \equiv \int_{-\infty}^{d} \frac{e^{-z^2/2}}{\sqrt{2\pi}} dz$ is the univariate standard normal distribution function,

$$d_1(\frac{V}{K_2}e^{-\delta\tau}) \equiv \frac{\ln(\frac{V}{K_2}e^{-\delta\tau}) + \sigma^2\tau}{\sqrt{\sigma^2\tau}},$$

$\delta \equiv \delta_V - r$, $\sigma^2 \equiv \sigma_V^2$,

and $d_2(\frac{V}{K_2}e^{-\delta\tau}) \equiv d_1(\frac{V}{K_2}e^{-\delta\tau}) - \sigma\sqrt{\tau}$.

Therefore, the two-stage investment opportunity can be considered as buying a European call option by paying K_1. If $F(V, K_2, \tau) \geq K_1$, then the investment should be undertaken, otherwise it should be denied.

Note that the two-stage investment above is just a special case of multi-stage investments. A true multi-stage investment can be treated as a *compound option*, an option on another option on another…and so on. Also in a more general case, K_2 should be a *stochastic* variable since a multi-stage automation/ robotics investment typically involves significant *technical related uncertainty* that will be resolved only after the initial/first stage investment. Interested readers can find further references in McDonald and Siegel's work [8].

4.3 An illustrative example

Suppose that GrowthCom, an international construction firm, is evaluating an automated fire-proofing robotic system. The investment includes the first stage of 3-year R&D and second stage of robots production and system implementation. The first stage requires a fixed cost of K_1= \$3*m*. Suppose the second stage's cost at year 4, K_2, is also fixed and K_2 = \$14*m*. The automation system will help GrowthCom expand his market to other regions. However, the actual benefit is uncertain and depends on the global construction market conditions. The expected present value of the benefit is \$20*m* should the project be completed *today*. Suppose that the expected benefit follows equation (1) with $\mu_V = 0$ and σ_V =0.25. Other estimates include $\mu_{VS} = 0.12$, $\delta_V = 0.12$ and r=0.05. Should GrowthCom invest or not? What is the value of the investment opportunity?

If we use the conventional NPV approach, the *contingent* future investment profits will be difficult to assess. Although conventional decision tree technique can be used for contingent future investment, the determination of corresponding discounting rates is difficult and subjective. However, if we apply the option pricing theory framework and compute the value using equation (7), we may obtain the value of the second stage investment opportunity $F(V, K_2, \tau)$ =\$3.30*m*, when V=\$20*m* and K_2=\$14*m*. Note that this value is consistent with market opinions instead of decision maker's subjective risk attitude. Since this option value is greater than the first stage investment, \$3*m*, GrowthCom should *undertake* the investment.

4.4 Multi-stage investment strategies and growth options

Kester [9] showed that "growth options" may "constitute well over half of the market value of many companies' equity". Growth options are the options created by an investment project to make follow-on investments should market conditions turn out to be advantageous. The R&D projects and the automation/ robotics investments can be considered as this type of investment that creates growth options. The two-stage investment valuation framework demonstrates its strengths in pricing and quantifying the *strategic value* of such investments.

The example above shows that the option to stop or continue in a two-stage investment creates values. Thus if a successful technology development can place a firm in a leading position by creating competitive advantages; then, to invest or implement an "unprofitable" and "risky" pre-matured automation/robotics technology may be justified by considering its strategic value.

The sensitivity analysis shows that higher σ_V does not necessarily make a project more valuable. It can also be inferred that to divide an investment into several *stoppable stages* is desirable due to the managerial options embedded.

5. CONCLUSIONS

This paper presents a method for evaluating automation/robotics investments based on modern option pricing theory. In single-stage investments, investment threshold is generally higher than that from conventional rules due to the timing option. Higher industry/business volatility or lower investment competition usually suggests higher threshold. In a complex multi-stage investment, we focus on its option to stop or continue at the beginning of each stage. The framework can also be applied to value *strategic* investments' indirect benefits such as competitive advantages and growth opportunities.

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