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Economic Assessment of APC and RTO Using Option to Expand

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Abstract. This paper aims to develop a new economic assessment (EA) method using the option to expand for Advanced Process Control (APC) and Real Time Optimization (RTO). The new EA criteria for investment decision for APC and RTO employ net present value of APC and call option of RTO. Calculation of call option adapts arithmetic measurement method to compute annualized volatility. The new EA applies scenario analysis to take appropriate action. There are four scenarios and their corresponding actions, namely, (1) safe scenario - invest only APC, (2) value-added scenario and (3) risky scenario - invest in APC and RTO, (4) gamble scenario - reject APC. Furthermore, early exercise criterion for RTO investment uses American option method. Applying new EA method to VCM plant demonstrates the effectiveness of the option to expand. The results show that when NPV of APC is negative and the sum of NPV of APC and Call of RTO is positive, APC project is risky scenario. We recommend to invest in APC and RTO. In comparison to conventional NPV and Payback Period (PB) methods, APC is not feasible since NPV is negative and PB is not available due to negative expected profit. In the case study, volatility calculation addresses only one product line in chemical industry which is VCM. Real production comprises of multiple product lines and their volatility is larger than that of one product. With the new EA method, management has comprehensive and flexible tool to assess APC/RTO benefits. Moreover, the new EA provides the timing to invest RTO. Profit margin, expiration period and yield are key parameters that affect early exercise. The new EA is the first method to apply real options to APC and RTO which evaluates the benefit not only APC but also the integrated APC and RTO. The early exercise criterion can facilitate the decision maker to invest in the most beneficial period.

Keywords: Option to expand, real options, economic assessment, decision support, early exercise criterion, flexibility.

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1. Introduction

Economic assessment plays a vital role for industrial investment process. Feasibility study is required to consolidate the information that is related to investment decision making. The result of the study comes in terms of the financial decision whether the project is worthwhile. Typically, Advanced Process Control (APC) project employs conventional economic assessment such as Net Present Value (NPV) and Payback period (PB) methods to find the economic benefits described by positive present values and months of payback period. Conventional methods usually fix the feasibility project with rigid business environment. As a result, they can answer only 'Go/No Go'. Despite the convenience of use, they do not support flexibility to respond economic uncertainty. The firm might under value the first investment and has a strategic option to expand the investment which is not an obligation.

Real options have additional benefit from the conventional assessment methods because it takes into account of uncertainties from external parameters and opportunities of the on-top project that arise from business situation [1]. The term 'Expanded NPV' (ENPV) has introduced [2] to mark up the traditional NPV with additional option value. The flexibility of investment decision comes from the ENPV which can be measured by the expanded value of options itself or even the development of value of flexibility [3]. In practice, there are many types of real options such as option to expand, option to defer that have been used in varieties. However, to the best of knowledge, there is no work showing how to apply real options to Industrial Automation and Control System (IACS).

In this paper, we explore the feasibility study of APC investment project by employing the principle of option to expand [1, 4, 5].The option to expand approach allows flexibility in decision making process to the firm by considering the second investment opportunity, Real Time Optimization (RTO), on top of the first investment, APC. The objective of this paper is to improve the economic assessment (EA) method for integrated APC and RTO. In particular, decision process with scenario analysis is developed for APC project. It can categorize the feasibility result into four different scenarios, namely, value-added, safe, risky, and gamble. Furthermore, we develop early exercise criterion to determine an appropriate timing to invest RTO project by applying time series analysis and volatility calculation of profit margins. The contribution of this paper is a novel decision support system of EA based on the option to expand approach with application to APC and RTO.

The paper is organized as follows. In section 2, we review the conventional economic assessment methods. In section 3, we elaborate the decision support system based on the option to expand approach. It includes NPV of APC project, volatility estimation, call value of RTO project decision process with option to expand. In section 4, we develop early exercise criterion for making decision when to exercise the option. We demonstrate an application of the option to expand approach to a VCM plant case study in section 5. Finally, the discussion and conclusions of the research are given in section 6.

2. Conventional Economic Assessment

In this section, we review the conventional economic assessment method that is used among the end users and the vendors. We focus on the feasibility study using Net Present Value and Payback Period for APC projects and their limitations.

2.1. Net Present Value

In general, free cash flow (FCF) model comprises four terms as follows:

$$FCF = NP + IE - CE - WC$$

where NP is Net Profit, IE is Interest Expense, CE is Net Capital Expenditure and WC is Net Change in Working Capital which is equal to Current Assets minus Current Liabilities. We assume that all transactions of investment in the project are made by cash. Thus, we do not consider inventory, current liability and current loaner. As a result, the net change in working capital is zero and the interest expense is zero. FCF model can be simplified as follows:

$$FCF = NP - CE$$

In such case, *FCF* is referred to as Net Present Value (NPV). NPV deals with the financial FCF in each year and the sensible discount rate to discount cash flow back to net present value. NPV of the APC project is determined by using the expected profit as cash inflow, considering the APC project lifetime and the APC project investment cost. NPV is defined to be the net difference of the present value of cash inflows and the present value of cash outflows.

$$NPV_{APC} = \sum_{i=1}^{T_0} \frac{EP_{APC,i}}{(1+WACC)^i} - K_{APC} \tag{1}$$

where NPV_{APC}= net present value of the APC project (M$),
$EP_{APC,i}$= expected profit at the i^{th} year of the APC project (M$/yr),
T_0= lifetime of APC project (yr),
$WACC$ = weighted average cost of capital (%/yr),
K_{APC}= APC initial investment cost (M$).

Note that WACC is obtained by using the profit data from annual report of the owner company. To compute the expected profit (EP) of APC project, we first calculate

$$PM_i = \frac{1}{n}\sum_{j=1}^{n} PM_{i,j} \tag{2}$$

where PM_i = Average profit margin of product at the i^{th} year ($/ton) and
$PM_{i,j}$ = Profit margin of product at the j^{th} period of the i^{th} year ($/ton).

EP of APC project at the i^{th} year can be calculated as follows:

$$EP_{APC,i} = PM_i \times Y_{APC} \times R \times SR \tag{3}$$

where Y_{APC} = Yield increase from APC project (tons/hr),
R = Machine running hour per year (hrs/yr), and
SR = Service rate (%).

All of the parameters in Eq. (3) can be considered as downside risk of the APC project. Especially, PM is external parameter that causes uncertainty of expected profit. The criterion of investment decision is typically based on NPV itself. If NPV has positive value which means the combined present value of all cash inflows exceeds the present value of cash outflows, then the project is financially feasible. Otherwise, the project is rejected.

According to Sullivan (2012), Minimum Attractive Rate of Return (MARR) is another means to make investment decision. It is defined as

$$MARR = WACC + PA + PR$$

where *PA* = project administration (%) and *PR* = project risk (%). *PA* and *PR* can be varied from person to person. The decision is based on Return of Investment (ROI) principle. There is a relationship between *ROI* and *NPV*. For instance, 'GO' decision is made for investment project if *ROI* is greater than *WACC*. This criterion is equivalent to *NPV* > 0. In our study, we do not use *MARR* to discount cash flows but employ *WACC* to discount cash flows because it reflects the real cost of capital to generate cash flow based on *NPV*. Moreover, the volatility of *NPV* comes from the real historian data which is not subjective.

The major limitation of NPV method is the difficulty to obtain the accurate future costs and benefits and no universal discount rate [6]. To overcome this limitation, other analysis tools such as expected value tables, decision trees, weighted score table, sensitivity analysis can be considered as a supplemental financial assessment tool. Other limitation of NPV method is that the project takes into account only when its present value is positive. In other words, the investment process stops if the NPV is zero or negative. This reflects a rigid decision which is not flexible to consider other opportunity in the investment decision process.

Payback Period: Payback Period is defined by the initial investment cost (K) divided by expected profit of APC project at the i^{th} year as follows:

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$$PB = \left(\frac{K}{EP_{APC,i}}\right) \times 12 \qquad (4)$$

where $PB =$ payback period (month) and $EP_{APC,i}$ is given in Eq. (3). In view of investment decision criterion, the calculated PB is compared to typical payback period of the same industry. If the calculated PB is equal or less than the typical payback period then the project is feasible. Otherwise, the project is rejected. Note that when PM turns out to be a negative value, the calculated EP becomes negative value. In such case, the calculation of Eq. (4) becomes negative value but PB is considered not available (N/A), and the project is not feasible.

The limitation of the payback period method is that the project benefits do not take into account for the total benefits after the consideration period and time value of money is ignored [7].In addition, the PM calculation employs only the historical data which strongly depends on the economic and business situation. Like NPV, the PB method does not provide any flexibility for the management to consider other opportunities as an on-top benefit to the investment project. As a result, the PB method is a static decision method.

Both NPV and PB methods have disadvantages on the decision making. Therefore, we will explore the real options approach and investigate how to apply real options to feasibility study of APC and RTO.

3. Option to Expand for APC and RTO

For automatic control application, we install Distributed Control System (DCS) as a basic process control system. DCS is considered as a prerequisite system for other on-top systems. The controllers related to DCS include Proportional, Integral and Derivative (PID) and Programming Logic Control system (PLCs).Advanced Regulatory Control (ARC) is referred to as advanced control techniques, such as feed-forward control and override control which is typically implemented using function blocks or additional control programming at the DCS level. In order to improve performance of the process, APC and RTO are deployed as the on-top systems. RTO aims to optimize the set point values which are calculated on a regular basis such as every hour or every day. Additional benefits of RTO come from an economic objective optimization for all advanced process controllers. Figure 1 displays the proportion of investment and the potential of improvement for the on-top systems [8].

Real options can be divided into many methods including "option to defer" and "option to expand". We have already developed option to defer for APC [9]. In this paper, we will develop option to expand and apply it to APC. As explained in Damodaran (2002), option to expand has the following principle: "Firms take projects because doing so allows them either to take on other projects or to enter other markets in the future. Even though a project may have a negative NPV, it may be a project worth taking if the option provides the firms a more-than-compensating value."

In this study, we assume that the plant has already installed DCS and ARC. APC project is considered as the first investment and RTO project is considered as an option for the second investment.

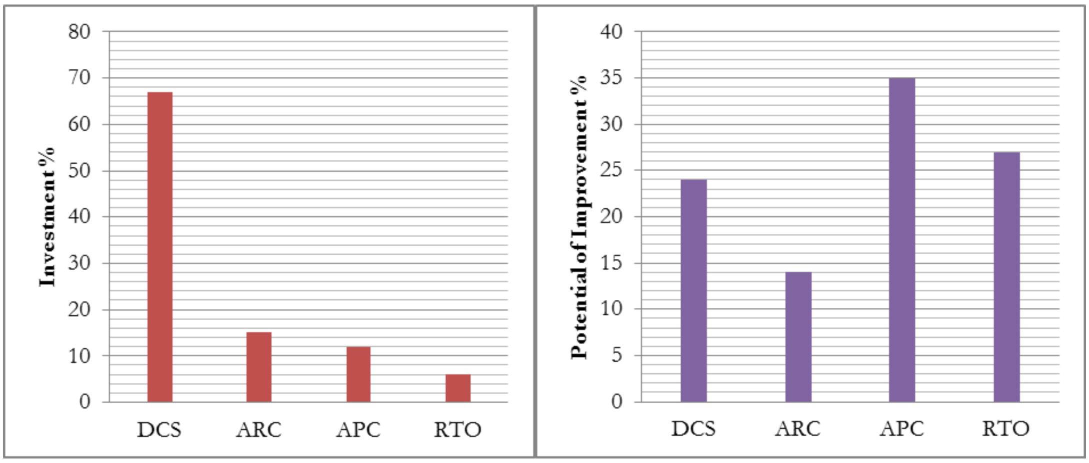

Fig. 1. Investment and potential of improvement for on-top systems.

3.1. Volatility Calculation

Volatility is one of the important parameters to calculate the real options value. It measures the uncertainty and the variation of the total value of the underlying asset over the project lifetime. The volatility estimation is one of the difficulties in the real options [1, 10-12]. According to Mun (2003), volatility is the most difficult input parameter in real options analysis. The research by David et al. (2011) reports that there were many methods developed to calculate volatility but they question how efficient these methods are. There are no consensus on which theoretically justified approach is the most efficient method to compute the volatility for real options [12]. In general, there are two types of volatility [13-15]:-

i. Historical volatility—to estimate volatility using the historical data of the price.
ii. Implied volatility—to estimate volatility until the option price has volatility match with the predicted Black-Scholes model price.

Previously, the calculation of stocks volatility uses the 'Logarithmic Returns' method which is direct approach as it is referred to the variability of the cash flow estimates that are used in calculating the underlying asset value. The advantage of this method is simple to use, mathematically valid, consistent with the assumed variability of the cash flow. The meaning of the logarithmic returns is the returns or the changes of two period's values by using logarithmic function. The logarithmic returns are primarily used in this calculation because the asset price paths typically follow geometric Brownian motion (GBM) or exponential Brownian motion which is a random motion. A GBM is useful for stock prices modelling over time when the percentage changes are independent and identically distributed [16]. The mathematical model of GBM has numerous real-world applications in which the stock market fluctuation is a good example. In particular, it is used for the mathematical financial modelling of the stock prices in the Black–Scholes model. Assets follow GBM and continuous time return should be measured using natural logarithms [17]. However, this method has disadvantage over the mathematical models used to forecast the cash flows, such as, time series analysis may not fit.

We observe that there is a difference between the volatility methods used for stocks and investment options. The volatility method used for stocks assumes lognormal distribution to reflect the fluctuation from zero to positive value. For investment options, volatility of the investment options is estimated from profit margin which can be either negative, zero or positive value. Negative value of profit margin means that the cost of the product is actually higher than the revenue generated from the sale. When profit margin has negative value, the return associated with the value will be a negative number, for which a natural logarithm does not exist. [11, 12]. Profit margin is an external parameter based on economic situation which is out of control by the project. It is observed from the historian data that it is possible to have highly fluctuated profit margin, such as, from positive to negative and vice versa. Thus, high fluctuation of profit margin can lead to a large volatility.

We review other volatility estimation methods including Translated Logarithm [18] and Arithmetic Measurement [17].These methods can handle negative value. Arithmetic Measurement (AM) fits into BS model for APC and RTO. Translated Logarithm requires level shift which cause variation to have different meaning whereas Arithmetic Measurement does not change the meaning of variation, thus it is appropriate to determine the volatility. If the markets follow GBM or random motion, then this AM solution is practical and gives reasonable result as a continuous time GBM. Volatility plays a crucial role in a real options analysis since the option value depends on the volatility of the underlying asset, namely, RTO. Historical volatility measures the variation of profit margin (PM) of the product over time. NPV_{RTO} has been calculated as cash flow of the project. We manage to specify the related parameters to obtain EP as given in Eq. (3). In our study, Y, SR, R are fixed for all scenarios and only PM_i is considered as variable. Thus, cash flow has direct relationship with PM_i. We use PM_i and PM_{i-1} for volatility calculation.It is worth noting that historical volatility can lead to annualized volatility. The annualized volatility is the standard deviation of yearly relative PM changes. The following algorithm shows how to compute annualized volatility [13, 15, 19].

Step 1: Compute the relative PM change $x_i$as follows:

$$x_i = \frac{PM_i - PM_{i-1}}{|PM_{i-1}|} \tag{5}$$

where PM_i is the PM of the i^{th} period and PM_{i-1} is the PM of the $(i-1)^{st}$ period.

Step 2: Compute the average of relative PM changes x as follows:

$$x = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{6}$$

where n is the number of relative PM changes.

Step 3: Compute the standard deviation (σ) as follows:

$$\sigma = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x_i - x)^2} \tag{7}$$

The historical volatility is equal to this standard deviation.

Step 4: Compute the annualized volatility σ_T by multiplying the historical volatility in Eq. (7) by the square root of the time factor as follows:

$$\sigma_T = \sigma\sqrt{t} \tag{8}$$

where $t = 4$ (to convert quarterly basis into yearly basis) or 52 (to convert weekly basis into yearly basis) or 252 (to convert daily basis into yearly basis).

3.2. Call Value of RTO

The option can be classified into 2 categories, namely, call option and put option. The call option is the right for the holder to exercise (invest) and the put option is the right for the holder to sell (disinvest). In this study, we are interested in an option to extend its investment from APC to RTO. Thus, it is a call option. Call options for stock have a dividend payout to consider whereas call options for project may use loan or accumulated profit for project investment. There is no dividend exercised in our call options. We consider the cost of waiting as a 'time premium' associated with the remaining life of an option and develop the mechanism for early exercise criterion in the next section.

Let S be the value of RTO which is defined as the total expected profit of RTO.

$$S = \sum_{i=1}^{T_2} EP_{RTO,i} \tag{9}$$

where $EP_{RTO,i}$ = expected profit at the i^{th} year of the RTO project (M$/yr), and
T_2 = the life time of RTO project.

We apply the Black-Scholes (BS) model [5, 19-21] with the basic assumptions, such as, the volatility is constant over the life time and the real asset future path is symmetric. Let $Call_{RTO}$(M$) be the call value of RTO which is defined as follows:

$$Call_{RTO} = SN(d_1) - K_{RTO}e^{-rt}N(d_2) \tag{10}$$

where K_{RTO} = investment of RTO (M$),
r = riskless interest rate corresponding to the life of the option (%),
t = time to expiration of the call option (yr),
$N(d_i)$ = standard normal cumulative distribution function,
d_1 = factor that the present value of contingent receipt exceeds the project investment cost,
d_2 = risk-adjusted factor that the option is exercised.

$$d_1 = \frac{\ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma_T{}^2}{2}\right)t}{\sigma_T\sqrt{t}}, \quad d_2 = d_1 - \sigma_T\sqrt{t}$$

The decision criterion of the APC investment is to take the option that provides a more-than-compensating value, namely,

$$NPV_{APC} + Call_{RTO} > 0 \tag{11}$$

When the criterion (11) is not satisfied, it means the RTO project has not enough additional value to cover the negative value of NPV_{APC}. Therefore, the management can make a decision not to invest in APC.

3.3. Scenario Analysis

We develop the scenario analysis which aims to support the decision making process of integrated APC and RTO feasibility study. Scenario analysis utilizes both NPV_{APC} and $Call_{RTO}$. Impact of profit margin reflects in terms of NPV_{APC}. Uncertainty of volatility reflects in terms of $Call_{RTO}$. Both variables involve in the decision process which is categorized into four scenarios, namely, value added, safe, risky, and gamble. We modify four scenarios to serve the APC investment [22]. Figure 2 depicts the scenario analysis for the option to expand. The horizon axis is referred to $Call_{RTO}$ and the vertical axis is referred to NPV_{APC}.

Fig. 2. Scenario analysis for the option to expand.

Value-added scenario is a case when both NPV_{APC} and $Call_{RTO}$ are positive. This is the best scenario. By conventional NPV analysis, we can make a decision to invest because APC project yields a positive NPV with low volatility. Moreover, RTO project provides additional value to the overall benefits. We can decide to invest in APC project. For RTO project, we can use timing to exercise method to select an appropriate time for investment to enhance highest value. We will present the method in the next section.

Safe scenario is a case when NPV_{APC} is positive and $Call_{RTO}$ is zero. It means that the APC project has benefit but there is no additional benefit from RTO project. Hence, the decision is to invest in APC project only.

Risky scenario is a case when NPV_{APC} is negative and $Call_{RTO}$ ispositive. It means that the APC project itself is not worth of investment. However, if we have an additional value from the RTO project which covers the loss from APC project, that is, $NPV_{APC} + Call_{RTO} > 0$, then the decision is to invest in APC. For RTO project, we can use timing to exercise method to determine an appropriate time for investment.

Gamble scenario is a case when both NPV_{APC} and $Call_{RTO}$ are negative. This is the worst scenario. It means that APC project results in loss and there is no additional value from the RTO project. Therefore, the management shall reject the investment of APC and RTO projects.

3.4. Decision Support System with Option to Expand

The decision support system starts with NPV calculation of APC. There are 2 possible cases of NPV, namely, $NPV_{APC} > 0$ or $NPV_{APC} \leq 0$. Applying scenario analysis as in Fig. 2, we categorize decision into four scenarios. Figure 3 gives the flowchart of the decision process.

For positive NPV_{APC} case, the APC is usually considered as a feasible project and the decision process is typically complete. In our study, we further apply the option to expand to calculate call value. If the call value of RTO is positive, $Call_{RTO} > 0$, then it is categorized as 'value-added scenario'. Both APC and RTO investments are valuable to invest. If the call value of RTO is zero or negative, $Call_{RTO} \leq 0$, it is categorized as 'safe scenario'. It means that the APC investment is feasible but no additional benefit from the RTO investment.

For negative NPV_{APC} case, APC is usually considered as infeasible project. Applying the option to expand, RTO investment is considered as additional opportunity. If $NPV_{APC} + Call_{RTO} > 0$, then it is categorized as 'risky scenario' which means RTO can cover the loss from APC project. Thus, both investments can go ahead with the awareness that we take some risk since the RTO investment is compensating the negative cash flow from the APC investment. If $NPV_{APC} + Call_{RTO} \leq 0$, then it is categorized as 'gamble scenario' which is the worst scenario and both investments shall be rejected.

4. Time to Exercise the Option

The purpose of this section is to determine an appropriate time to exercise the option to expand. Typically, the Black-Scholes (BS) model uses European option which the investment shall be made only at the end of expiration period. On the other hand, the exercise period of the American option can be any time before expiration and include at the end of the expiration period. In this paper, we apply the American option to the decision process of RTO. The longer the period before expiration is, the higher the call value is. The American option is more valuable than the European option, and is more complicated to value it. This rationale is in compliance with the time premium associated with the remaining life of an option.

Following the replicating portfolios principle, the BS model has the call option as follows:

$$\text{Call Value} = SN(d_1) - Ke^{-rt}N(d_2)$$

The first term $SN(d_1)$ means the buy amount that the company obtains the project with the value of expected profit of the project. The second term $Ke^{-rt}N(d_2)$ means the borrow amount that the company invests in the project. $N(d_1)$ and $N(d_2)$ represent the probability that the option will be in-the-money at expiration period which is equivalent to the probability that $S > K$. $N(d_1)$ is the probability by which the present value of contingent receipt exceeds the project investment cost and $N(d_2)$ is the risk-neutral probability that the option can finish with in-the-money [23].Typically, $N(d_1)$ is greater than $N(d_2)$. $SN(d_1)$ represents an upper bound of the call option [23].If call value is in-the-money or $S > K$, we will exercise the option at the expiration period. On the other hand, if it is out-of-moneyor $S < K$, we will not exercise the option.

The option to expand using the BS Model has limitation, especially with required assumptions. For examples, the project volatility is constant over the time and the real asset future path is symmetric [4, 5]. In our study, there is the variation on profit margin which make volatility fluctuated over the time. Next, we will investigate the impact of volatility to the decision of exercise period.

4.1. Early Exercise Consideration

For financial options, the American option is likely to exercise at the expiration period. Generally, the early exercise is not optimal because the time premium associated with the remaining life of the option makes it worth enough to wait until the end of expiration period and transactions cost makes early exercise not optimal. However, there are two exceptions to this principle as mentioned in [24].

> *"One is a case where the underlying asset pays large dividends, thus reducing the value of the asset, and any call options on that asset. In this case, call options may be exercised just before an ex-dividend date, if the time premium on the options is less than the expected decline in asset value as a consequence of the dividend payment. The other exception arises when an investor holds both the underlying asset and deep in-the-money puts on that asset at a time when interest rates are high. In this case, the time premium on the put may be less than the potential gain from exercising the put early and earning interest on the exercise price."*

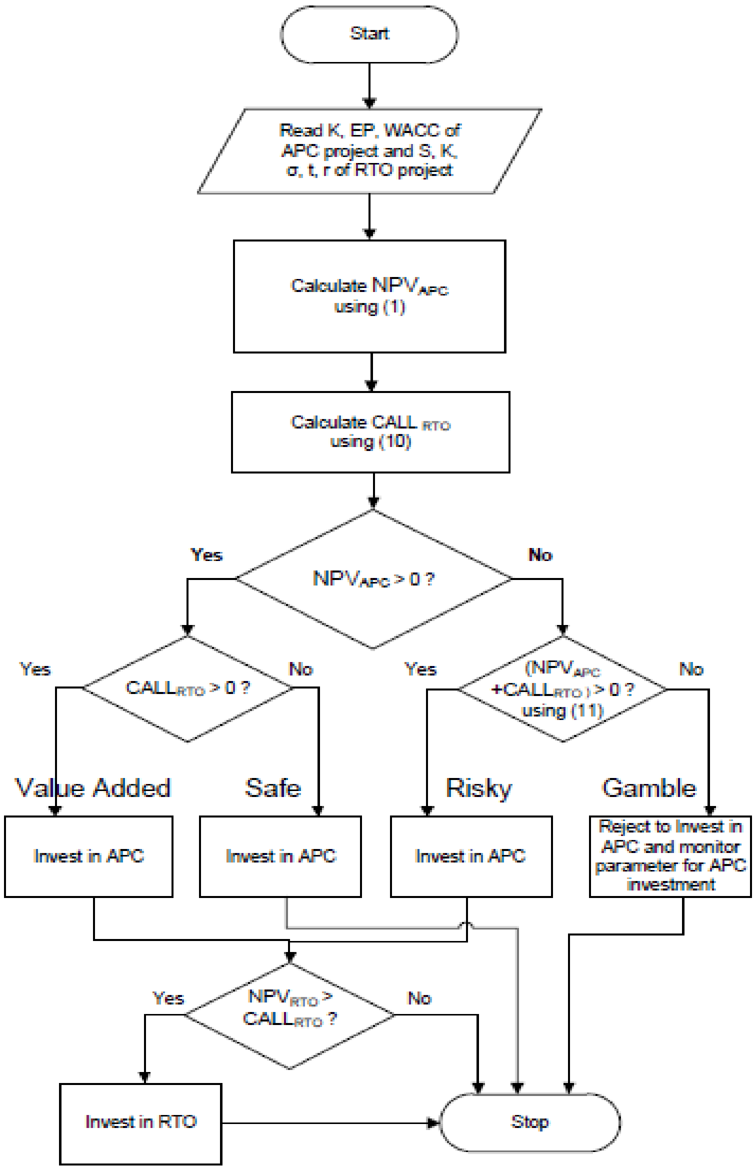

Fig. 3. Flowchart of decision process using the option to expand.

For real options, the American option is more likely to exercise at the end of expiration period since the underlying asset, or the project, has no dividend to pay to the holder. Moreover, the holder does not consider to put or sell the project. Conventional NPV is given by cash inflow minus cash outflow or *S*-*K* as per Eq. (1). Applying the real options method, the call value is calculated using Eq. (10). It is noted that the difference between conventional NPV and the call value comes from the uncertainty parameter, namely, standard deviation shown as annualized volatility in BS model [25]. Thus, early exercise is made when NPV of the considered RTO is greater than the call value at the potential exercise period. In particular, we will invest in RTO when $NPV_{RTO} > Call_{RTO}$. Otherwise, when the call value is greater than NPV of the considered project in any potential exercise period, the management should hold the option.

4.2. Early Exercise Criterion

As mentioned earlier, the BS model is designed for the European option. The considered options are the American option. Thus, we will develop a mechanism for early exercise using the American option. There are three approaches given in [24]. Firstly, the BS model is used in conjunction with a minimum value or a floor value of a real option. Secondly, the BS model is employed to value the option at each potential exercise period. Thirdly, the Binomial Option Pricing Model (BOPM) is used to value the option. The first approach cannot answer the exact value of the American option at specific early exercise period and the third approach is difficult to estimate the prices of option for each node of binomial tree diagram. The second approach is applicable to our study to determine an early exercise mechanism.

We investigate the proper time to exercise the option to expand by simulating for each quarter rolling values of PM, EP, σ_T to compute NPV_{RTO} and compare with $Call_{RTO}$. There are different periods to consider between APC investment and RTO investment. Figure 4 displays the periods to calculate NPV of APC project and the call option. T_0= APC project life time (yr), T_1= call option expiration period (yr), and T_2= RTO life time (yr). To calculate NPV_{RTO}, we modify Eq. (1) as follows:

$$NPV_{RTO} = \sum_{i=1}^{T_2} \frac{EP_{RTO,i}}{(1+WACC)^i} - K_{RTO} \tag{12}$$

where NPV_{RTO}= the net present value of RTO (M$),
$EP_{RTO,i}$= the expected profit at i^{th} year of RTO (M$/yr), and
K_{RTO}= the RTO initial investment cost (M$)

Note that EP_i of RTO project is obtained from Eq. (3) by changing Y_{APC} to Y_{RTO} while the other parameters remain the same.

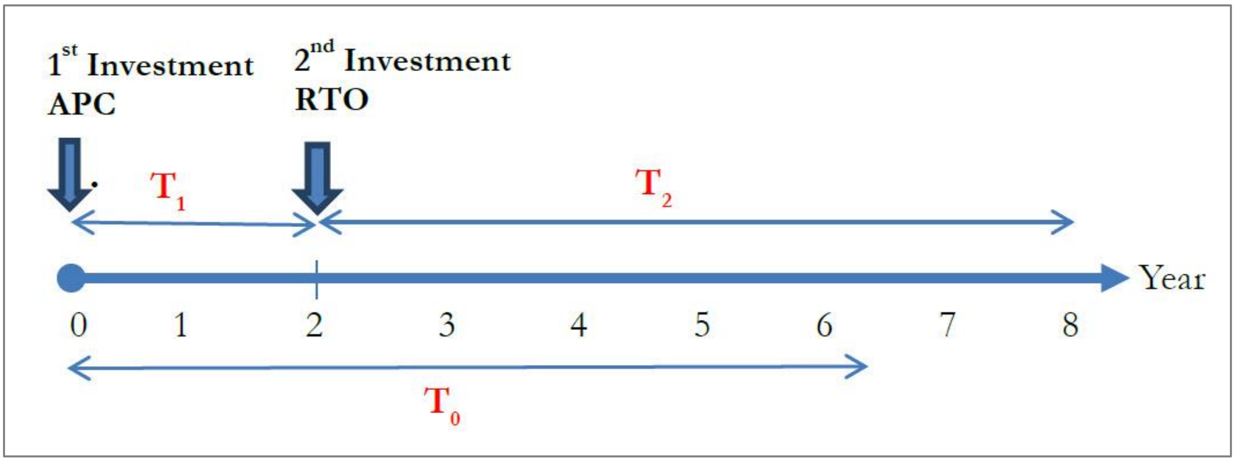

Fig. 4. Calculation period for option to expand.

Next, we propose a mechanism for early exercise criterion. The main concept is to vary the investment period while the expiration period of call option is held constant. It is possible that option exercise is not executed at expiration period, so the investment consideration can be moved to subsequent windows. The decision criterion to exercise the call option is based on the comparison between NPV_{RTO} and $Call_{RTO}$ for each investment window. If NPV_{RTO}> $Call_{RTO}$ at any window, then we will exercise the option to expand at that period. Otherwise, we move the investment to the next period. In summary, the American option is applied to a series of investment windows. Figure 5 demonstrates sliding windows concept for early exercise. The proposed mechanism behaves like the dynamic American option in contrast to the static American option. The criterion is quite logical since we hold the call option until the call value is less than NPV of RTO.

Prior to the early exercise algorithm, we apply the time series method to forecast PM as following steps:

a. Let t_0 represent present time and the historical data of *PM* be $PM(t_0 - N), \ldots, PM(t_0 - 1), PM(t_0)$ where N+1 is the total number of data points.
b. Divide the historical data of PM into two parts: a training dataset and a validation dataset.
c. Fit a model to the historical training data by specify ARMA(p,q) model
d. Forecast the fitted model over the validation period.
e. Compare the forecast model to the validation dataset using Predictive Mean Square Error (PMSE). We select the ARMA(p,q) model that has minimum value of PMSE. That fitted ARMA(p,q) model provides the best prediction performance.

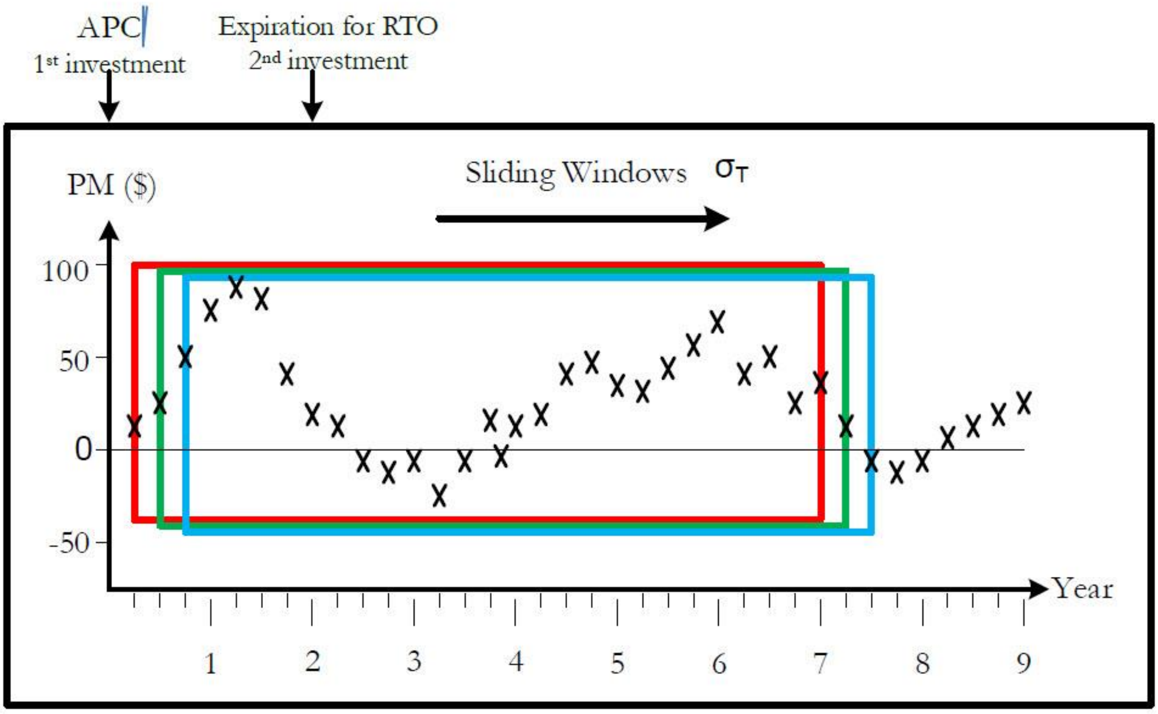

Fig. 5. Sliding windows concept for early exercise.

We explain the detail of the time series method to forecast PM [9]. From the pre-requisite information, then we employ the early exercise algorithm as follows. Let t_0 be initial time of consideration and T_1 be expiration period of call option.

Step 1: Let $t = t_0$. Let p be the time series consisting of $PM(t_0 - N), \ldots, PM(t_0 - 1), PM(t_0)$

Step 2: Calculate $EP_{RTO}(t)$ or $S(t), \sigma_T(t),\ K(t), Call_{RTO}(t)\ , NPV_{RTO}(t)$ based on the time series p.

Step 3: If $NPV_{RTO}(t) >\ Call_{RTO}(t)$ then invest in RTO at t and stop, else go to Step 4.

Step 4: Update p by removing $PM(t_0 - N)$ and appending $PM(t_0 + 1)$.

Step 5: Let $t = t + 1$. If $t < t_0 + T_1$ then go to Step 2, else invest in RTO at $t_0 + T_1$ and stop.

The result of this method provides the justification for early exercise of the option to expand. Note that when $t = t_0 + T_1$ and $NPV_{RTO}(t)$ still earn the value less than $Call_{RTO}(t)$, we will reset $Call_{RTO}(t)$ to zero and invest in RTO at expiration period.

5. Case Study of VCM Plant

We select a downstream chemical plant, namely, vinyl chloride monomer (VCM) plant in Thailand, as a case study. The conventional method of feasibility study has been done in 2010. The chemical compound 1,2-dichloroethane, which is known by the name of VCM dichloride (EDC), is mainly used to produce VCM. VCM is the major component for PVC production. The process diagram for VCM plant is shown in Fig. 6.

The VCM plant consists of EDC cracking, EDC purification, VCM purification, Oxy-Chlorination. The APC benefits are identified on the following.

- Increasing production while minimizing the effect on furnace run-length
- Improving steam savings on the EDC and VCM purification sections
- Reducing EDC loss in vacuum column
- Reducing VCM in Oxy-chlorination reactor

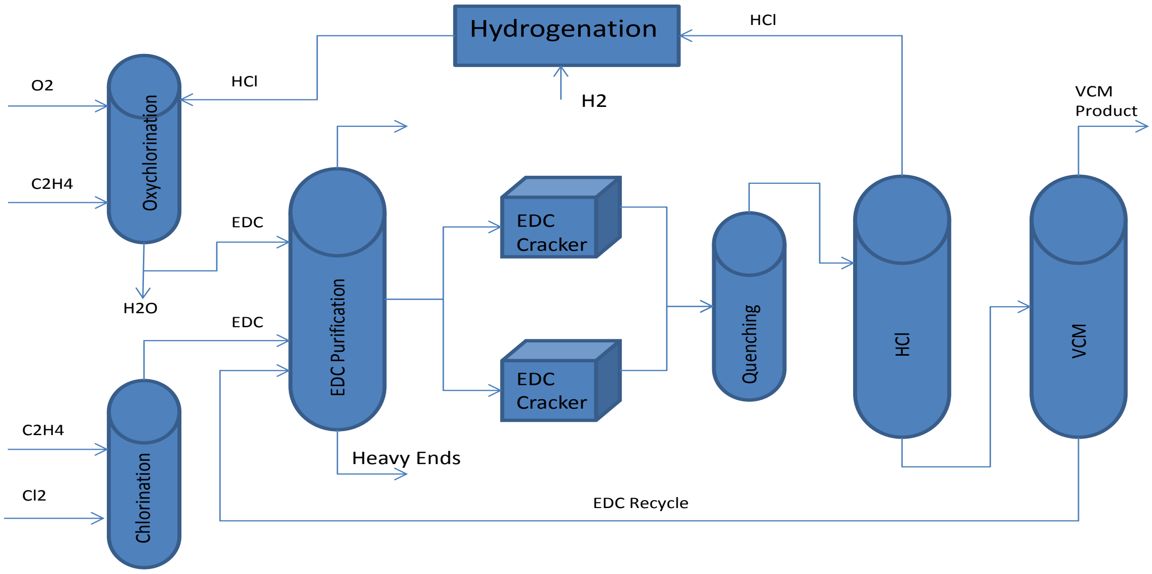

Fig. 6. Process diagram of VCM plant.

5.1. Conventional Assessment

Net Present Value: We start to calculate EP for VCM plant. Historical VCM profit margin during the year 2007-2010 had been collected by [26, 27]. The VCM profit margin ranges between -50 $/ton to 350 $/ton and is considered as uncontrollable parameter. The other parameters, namely, Y, R and SR are considered as the downside risk but can be controlled. These parameters are remaining the same for all scenarios. In this paper, we choose Y_{APC} = 1.76 tons/hr, R = 7920 hrs/yr, and SR = 0.9%.We create four scenarios to demonstrate the effect of PM. Scenario 1 using the average historical PM data. The other three scenarios will be used to demonstrate the limitation of the existing assessment tools.

We calculate NPV_{APC} using Eq. (1). The initial investment of APC (K_{APC}) is 0.34 M$. Based on historical data of the firm, $WACC$ is 11.5%. The lifetime of APC (T_0) is chosen to be 7 years as the hardware server and the Operating System of APC need to migrate to the new model. To obtain $EP_{APC,i}$, we use Eq. (3) to calculate the value for each scenario and the results are shown in Table 1. Using the conventional economic assessment, APC of scenario 1 and 2 is feasible since NPV is positive. However, APC of scenario 3 and 4 is not feasible since NPV is negative.

Payback Period: The expected profit of APC in scenario 1 and 2 is 1.03 and 0.63 M$/yr, respectively. Using Eq. (4) to calculate payback period, the calculated payback period is 4.0 and 6.5 months, respectively. We compare the calculated PB with typical payback period of the same industry. In this case, VCM plant is considered in chemical industry which the typical payback period is 3-6 month. Thus, scenario 1 yields an acceptable payback period, thus, the APC investment is feasible. On the other hand, scenario 2 has a little higher payback period. The firm can reconsider to invest in APC or wait until the economic condition (such as PM) changes. Typically, the management usually decides to invest in APC as it has long term benefits. For scenario 3 and 4, the expected profit of APC has negative value so PB is not available (N/A), thus the project is not feasible and the results are shown in Table 1.

In practice, there is economic uncertainty which makes PM fluctuated. We will apply the option to expand as an enhancement tool to evaluate the APC project for different scenarios.

Table 1. Calculation of NPV and payback period for APC Project.

Scenario	PM_i ($/ton)	$EP_{APC,i}$ (MS/yr)	NPV_{APC} (M$)	PB (months)
1	82.5	1.03	3.98	4.0
2	50	0.63	2.32	6.5
3	-5	-0.06	-0.55	N/A
4	-20	-0.25	-1.34	N/A

5.2. Option to Expand

For the option to expand, we need to calculate $Call_{RTO}$.We collect the related parameters involved the BS model in Eq. (10). Notice that PM, R, SR parameters for RTO are the same with APC. The different parameters are Y_{RTO} and K_{RTO}. To obtain yield increase for RTO (Y_{RTO}), RTO is considered to have 75% estimated additional benefit over APC [8]. We obtain initial investment cost for RTO (K_{RTO}) and calculate APC and RTO benefits and investment cost. The typical RTO investment cost is half of APC investment cost. Thus, we acquire K_{RTO} at 0.17 M$ compared to K_{APC} at 0.34 M$. We assume that RTO has project life time (T_2) of 7 years since it needs to renovate the operating system, hardware server, RTO software in the next seven years. From this information, we can calculate S as in Eq. (9).

Volatility Calculation: To obtain annualized historical volatility (σ_T), we use PM_i data of VCM from Q1/2007-Q4/2010 to calculate the standard deviation. However, the PM_i dataset of VCM has both positive value and negative value in a certain period. Thus, we apply Arithmetic Measurement method to deal with the negative case. The volatility calculation of VCM PM is shown in Table 2. The quarterly volatility is 1.71 and the annualized historical volatility is 3.42.

Table 2. VCM profit margin and relative PM changes.

Period	**Time (Quarter)**	PM_i (\$/ton)	$PM_i - PM_{i-1}$	$\frac{PM_i - PM_{i-1}}{\lvert PM_{i-1}\rvert}$
1	Q1/07	20		
2	Q2/07	-25	-45	-2.25
3	Q3/07	45	70	2.80
4	Q4/07	20	-25	-0.56
5	Q1/08	20	0	0.00
6	Q2/08	50	30	1.50
7	Q3/08	180	130	2.60
8	Q4/08	200	20	0.11
9	Q1/09	250	50	0.25
10	Q2/09	250	0	0.00
11	Q3/09	250	0	0.00
12	Q4/09	70	-180	-0.72
13	Q1/10	10	-60	-0.86
14	Q2/10	-30	-40	-4.00
15	Q3/10	-70	-40	-1.33
16	Q4/10	-90	-20	-0.29

Note that a production line comprises a series of processes and the volatility of PM of a production line will not be the same as the volatility of individual process. Typically, the volatility of production line is larger than that of an individual process. In this paper, we use PM of the product line to calculate the volatility. Volatility of an individual process is an interesting topic for future investigation.

Scenario Analysis: In order to demonstrate the scenario analysis, we divide the parameters for EP calculation into two groups. First group comprises Y_{RTO} $, SR, R$ which are fixed for all scenarios. These variables are internal parameters that relate to controllable risk. The other parameter is PM which is considered as external parameter and varies according to economic uncertainty and is not controllable. It is possible that PM is changing during the call option period of RTO. We assume PM is changing for the scenario 2 and 3. For scenario 2, PM is changing from positive to negative value and vice versa for scenario 3.

We choose the risk free interest rate to be 4% and specify time to expiration of option to expand (T_1) with two periods, namely, 2 and 3 years.We obtain $Y_{RTO} = Y_{APC} \times 0.75 = 1.76 \times 0.75 = 1.32$ tons/hr. In addition, R = 7920 hrs/yr, and SR = 0.9%.Then, we calculate $Call_{RTO}$ for each scenario as shown in Table 3.

Table 3. $Call_{RTO}$ of VCM plant.

Scenario	PM_i ($\$/ton$)	$EP_{APC,i}$ ($M\$/yr$)	Call RTO (M$) T1=2	Call RTO (M$) T1=3
1	82.5	7.837	7.824	7.834
2	-5	-0.232	0	0
3	50	2.179	2.172	2.177
4	-20	-0.881	0	0

Using feasible decision criteria as shown in the flowchart of Fig. 3, we calculate the value of $NPV_{APC} + Call_{RTO}$ and classify four scenarios shown in Table 4.

Table 4. Decision of feasibility study from different scenarios.

Scenario	NPV_{APC} (M$)	Call RTO (M$) $T_1 = 2$	NPV_{APC} +Call RTO $T_1 = 2$	Call RTO (M$) $T_1 = 3$	NPV_{APC} +Call RTO $T_1 = 3$	Type of scenario	Decision
1	3.980	7.824	11.804	7.834	11.814	Value Added	Invest in APC. Decide to invest in RTO using Timing to Exercise.
2	2.320	0.000	2.320	0.000	2.320	Safe	Invest in APC.
3	-0.550	2.172	1.622	2.177	1.627	Risky	Invest in APC. Decide to invest in RTO using Timing to Exercise.
4	-1.340	0.000	-1.340	0.000	-1.340	Gamble	Reject to invest in APC and monitor parameter for APC investment.

Scenario 1 gives positive NPV_{APC} and $Call_{RTO}$, thus the APC investment is value-added. Scenario 2 has positive NPV_{APC} but zero value for $Call_{RTO}$, thus the APC investment project is safe. For scenario 3, NPV_{APC} is negative but $NPV_{APC} + Call_{RTO}$ is positive, thus APC is risky. In scenario 4, APC has negative NPV and RTO project has negative call value, thus APC is gamble. It is observed that varying T_1 makes the call value of RTO slightly increases, but it does not affect the decision of feasibility study. From the results, the management has the flexibility to make a decision based on the most probable scenario by applying the option to expand.

5.3. Time to Exercise the Option

We determine an appropriate time to exercise the option to expand. The mean (μ) of historical data is at 72 \$/ton and the standard deviation is at 116 \$/ton. Other parameters are $WACC$ = 11.5%/year or 2.875%/quarter, Y_{RTO} =1.32 ton/hr, R=7,920 hr/yr, SR = 0.9.

As mentioned earlier in section 4.2, there are some steps which can be done before hand prior to use the early exercise algorithm. Starting with annualized volatility (σ_T) calculation, we can estimate volatility using the PM data in Table 2. The annualized historical volatility is 3.42. After that, we apply time series method to construct the PM model from historical PM data. We use the first 16 historical PM values as training dataset and the last 8 historical PM values as validation dataset in order to determine an appropriate ARMA model. Comparing the Prediction Mean Squares Error (PMSE) shown in Table 5, ARMA(9,7) model is chosen to be the most appropriate model.

Table 5. ARMA models and their PMSE.

Rank	ARMA Model	PMSE
1	(9,7)	793.6331
2	(9,5)	937.9043
3	(9,6)	1.53E+03
4	(8,1)	2.12E+03
5	(8,3)	2.59E+03

The selected ARMA model is given as follows:

$$\begin{aligned} F_{t+1} = 93.02 + 1.28PM_t - 0.44PM_{t-1} - 0.41PM_{t-2} + 0.40PM_{t-3} \\ -PM_{t-4} + 0.68PM_{t-5} + 0.28PM_{t-6} - 0.65PM_{t-7} + PM_{t-8} \\ -1.88F_t + 1.5F_{t-1} - F_{t-2} + 0.50F_{t-3} + 0.13F_{t-4} - F_{t-5} + 0.74F_{t-6} \end{aligned} \quad (13)$$

where F_t = forecast PM at time *t* and PM_t = actual PM at time *t*. Then, we use ARMA(9,7) model in order to forecast the VCM profit margin as shown in Fig. 7.

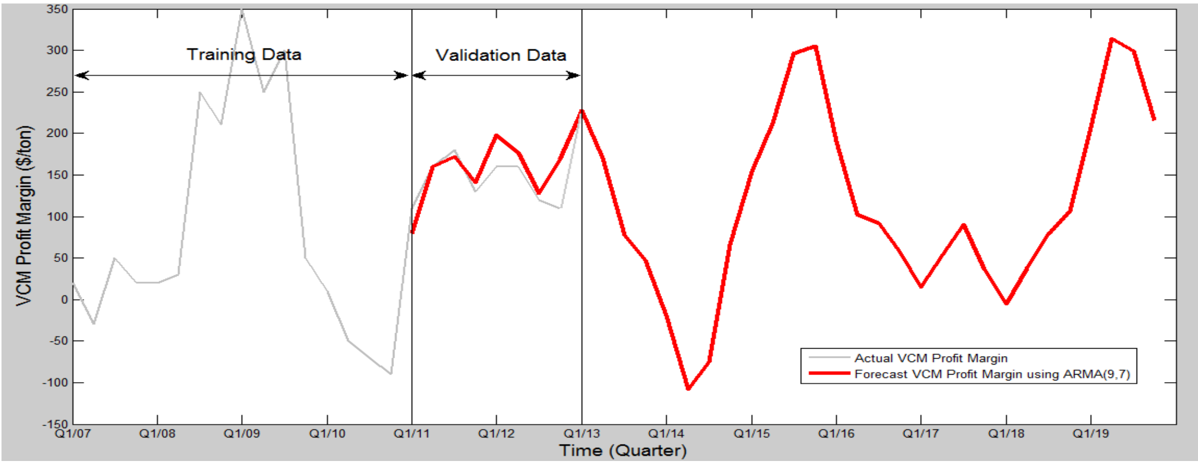

Fig. 7. Actual and forecast VCM profit margin.

Once we have those information on hand, then we use the early exercise algorithm to find out the appropriate period to exercise the option. After some iterations, the result in Table 6 shows that $Call_{RTO}(t)$ has greater value than $NPV_{RTO}(t)$ for all of quarters except the expiration period, thus we should hold the option and exercise at the expiration period which is Q4/2012.

Table 6. Timing to exercise for forecast VCM profit margin.

Time	Time to expiration - T(year)	K_{RTO} (t) (M$)	Forecast VCM PM ($/ton)	Annualized Volatility $\sigma_T(t)$	EP_{RTO} (t) (M$/ quarter)	Total cash inflow from EP_{RTO} (t)	NPV_{RTO} (t) (M$)	$Call_{RTO}$ (t) (M$)	NPV_{RTO} (t) - $Call_{RTOt}$	Decision
Q1/11	1.75	0.175	79	3.370	0.19	5.339	5.025	5.320	-0.295	No
Q2/11	1.50	0.180	160	3.074	0.38	5.302	4.988	5.260	-0.272	No
Q3/11	1.25	0.184	172	3.060	0.40	5.118	4.810	5.059	-0.249	No
Q4/11	1.00	0.190	141	3.062	0.33	4.944	4.640	4.862	-0.222	No
Q1/12	0.75	0.195	198	2.959	0.47	4.868	4.567	4.748	-0.181	No
Q2/12	0.50	0.200	177	2.566	0.42	4.763	4.465	4.587	-0.122	No
Q3/12	0.25	0.206	127	2.558	0.30	4.818	4.518	4.616	-0.098	No
Q4/12	0.00	0.211	169	2.563	0.40	4.976	4.672	0.000	4.672	Yes

5.4. Time to Exercise for Different Scenarios

In this section, we explore the value-added and risky scenarios which have potential to invest in RTO project. We generate the PM dataset using random normal distribution. We fix the volatility to be the same as the historical volatility, and vary average PM. After that, we use the early exercise algorithm and plot the value of $NPV_{RTO}(t)$ and $Call_{RTO}(t)$for both scenarios as shown in Fig. 8.

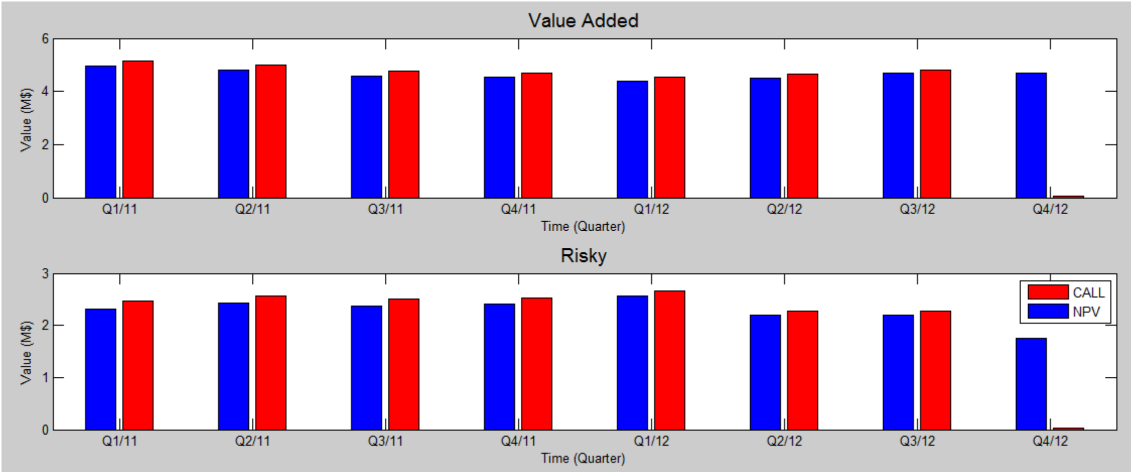

Fig. 8. Timing to exercise when the option expiration period is 2 years.

For value-added scenario, the total $EP_{RTO}(t)$ and $Call_{RTO}(t)$ are positive values. Thus, $NPV_{RTO}(t)$has positive value along the exercise period. We notice that $Call_{RTO}(t)$ has higher value than $NPV_{RTO}(t)$ along the exercise period until expiration period. Thus, the management should exercise for $Call_{RTO}(t)$ at Q4/2012 which is the expiration period.

For risky scenario, the total $EP_{RTO}(t)$ becomes positive value which results in positive value of $Call_{RTO}(t)$. Even though $NPV_{RTO}(t)$has positive value, it is less than $Call_{RTO}(t)$for all periods except at the expiration period. Thus, the management should exercise for $Call_{RTO}(t)$ at Q4/2012 which is the expiration period.

In both scenarios, it is recommended to wait and see during the exercise period since $NPV_{RTO}(t)$is less than $Call_{RTO}(t)$. The company still holds the right to invest until it is clear that NPV has higher value than that of the call option. Otherwise, RTO should be invested at the expiration period since it is the maximum period.

We change time to expiration of $Call_{RTO}$ from 2 to 3 years. The calculated results of two scenarios are shown in Fig. 9. For both scenarios, the total $EP_{RTO}(t)$ has positive value. Therefore, $Call_{RTO}(t)$ and $NPV_{RTO}(t)$ are positive. It is observed that the expiration period is longer, $Call_{RTO}(t)$ has higher value comparing to that with 2 years expiration. However, $Call_{RTO}(t)$ has more valuable than $NPV_{RTO}(t)$ all of the periods. Thus, the management should exercise for $Call_{RTO}(t)$ at Q4/2013 which is the expiration period.

In summary, the results show that the longer expiration period is, the higher call value is. There is no relationship between the period of time to expiration and the period of decision making since both $NPV_{RTO}(t)$ and $Call_{RTO}(t)$ are varied along the period.

5.5. Impact of Yield to Early Exercise Decision

In order to illustrate the impact of the yield of RTO over APC to the early exercise decision, we simulate a new PM dataset from Q1/2011-Q4/2013 and choose a different yield for two scenarios, namely, 'value added' and 'risky'. The new PM dataset gives the volatility equal to 2.337. The yield of RTO over APC is one of the factors in NPV_{RTO}. We vary the yield of RTO over APC, namely, 75%, 50%, and 25%. The results of two scenarios are shown in Figs. 10-12.

If $NPV_{RTO}(t) > Call_{RTO}(t)$at any period, then the management should exercise the option to expand at that period, which is referred to as 'early exercise'. For value-added scenario, when time to expiration is 3 years and yield is 25%, we observe that $NPV_{RTO}(t) > Call_{RTO}(t)$at Q3/2013. Thus, the management can make decision to invest on RTO at Q3/2013. On the other hand, when yield is 50% or 75%, $NPV_{RTO}(t) < Call_{RTO}(t)$for N data points. Thus, management should invest at the expiration period, Q4/2013.

For risky scenario, when time to expiration at 3 years and yield is 75% and 50%., we observe that $NPV_{RTO}(t) > Call_{RTO}(t)$at Q3/2013 and Q3/2013, respectively. Summary of the early exercise decision for varying yields of RTO over APC is shown in Table 7.

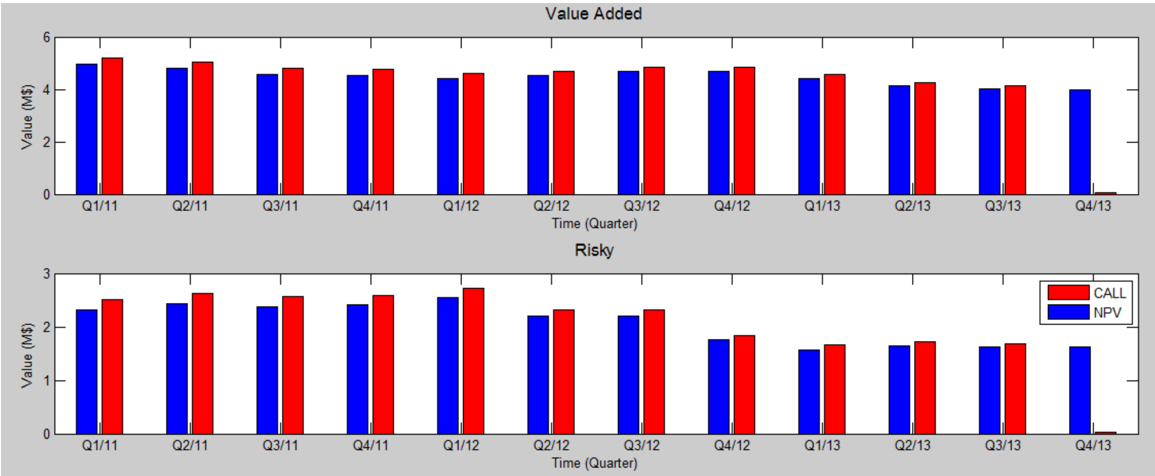

Fig. 9. Timing to expiration at 3 years for predicted PM dataset.

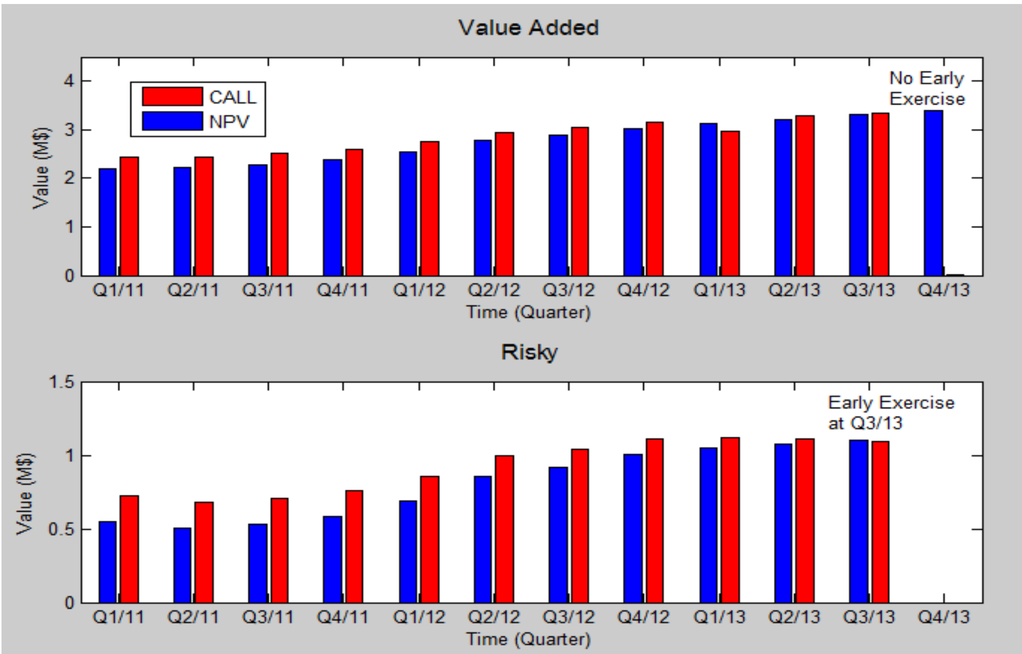

Fig. 10. Timing to expiration at 3 years for adjusted PM dataset and 75% yield.

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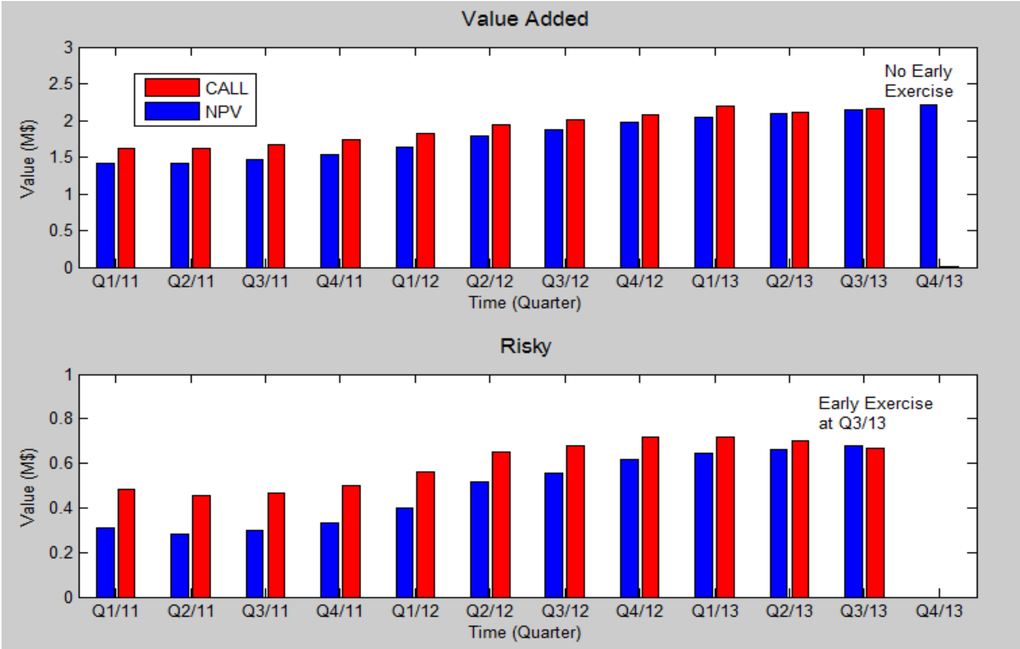

Fig. 11. Timing to expiration at 3 years for adjusted PM dataset and 50% yield.

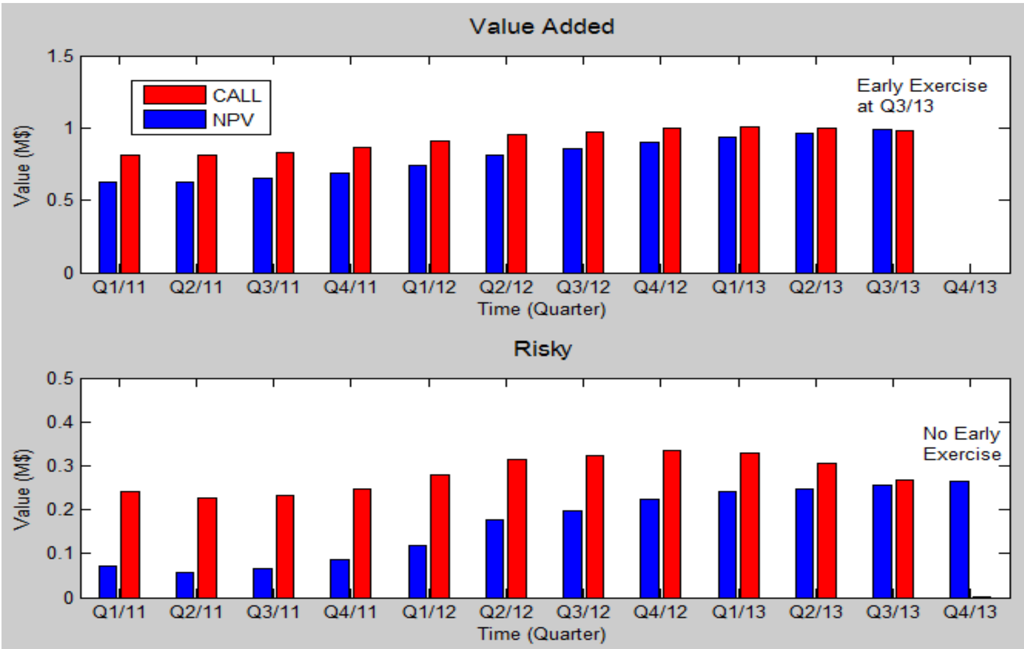

Fig. 12. Timing to expiration at 3 years for adjusted PM dataset and 25% yield.

Table 7. Impact of the yield to early exercise decision when time to expiration is 3 years.

Yield	Value Added Case	Risky Case
75%	No Early Exercise	Early Exercise at Q3/2013
50%	No Early Exercise	Early Exercise at Q3/2013
25%	Early Exercise at Q3/2013	No Early Exercise

6. Discussion and conclusions

Improvement of economic assessment method to evaluate APC project is addressed in this work. The option to expand method allows the management to take additional opportunities from RTO. The proposed method is applied to the case study of VCM plant. At the initial stage of the feasibility study of APC, the results of the option to expand are compared to that of conventional methods. Applying the option to expand for APC and RTO to the case study, we observe that the option to expand provides more flexibility in terms of on-top opportunities consideration. In this case, RTO is considered as a second opportunity. If the benefit from RTO can cover the loss from APC then the management has flexible decision to invest in APC. Scenario analysis developed for APC can facilitate the justification process to decide which case is the most suitable scenario for the plant. In the case study, we demonstrate the effect of external downside risk variable, PM, that impacts to different scenarios. The internal variables such as Y, SR, R have their own downside risk. The management has to monitor all of involved parameters to ensure that EP meets the target.

In conclusion, we develop the option to expand as an alternative investment decision support system for the integrated APC and RTO. In addition, we propose the novel method to determine appropriate timing to exercise the option for RTO. By applying the option to expand to APC and RTO of VCM plant, the proposed method provides the flexibility for investment decision making along the consideration period. Hence, the management can make a better decision under uncertainty in business environment.

It is possible to adopt the option to expand method for investment in other automation technology. Moreover, applying the complex real options and exercise conditions as in compliance with the method developed by [28] for IACS technology is the ultimate usefulness for real options since IACS have involved a wide variety of industrial automation portfolio, high performance technology, and complexity of EA justification.

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