Paper #147

Identification of Real Options "in" Projects

Tao Wang
Morgan Stanley
3 Exchange Square, Central, Hong Kong
bike@alum.mit.edu

Richard de Neufville
Massachusetts Institute of Technology
MIT, Room E40-245, Cambridge, MA 02139.
ardent@mit.edu (correspondent author)

Abstract

The concept of real options - initiated in the field of finance - has extended into engineering systems to model design flexibility in the realistically uncertain environment. However, whereas financial options are well-defined traded contracts, real options "in" engineering systems are a priori undefined, complex, and interdependent. Moreover, systems involve many more options than designers could consider. Therefore designers need to identify the real options most likely to offer good flexibility and the most value.

This paper proposes a procedure to identify real options "in" engineering systems. It consists of a screening and a simulation model. The screening model is a simplified, conceptual, low-fidelity representation of the system that reflects its most important issues. As it is inexpensive to run, it is used to test extensively designs under dynamic conditions. The following simulation model is used to validate critical considerations, such as the robustness and reliability of the designs, which are omitted from the screening model in order to expedite its operation.

The paper first establishes the concepts of the options identification model, and then resorts to examples to detail its application. The case of a hydro power system formulates the screening and simulation models, and presents the specific steps needed to search systematically for the interesting real options.

Background

Options are a way to define the basic element of flexibility. The technical concept of an "option" is a right, but not obligation, to do something for a certain cost within or at a specific period of time. This concept models flexibility as an asymmetric right and obligation structure for a cost within a time frame. This is a basic structure of human decision making – taking advantage of upside potential or opportunities and avoiding downside risks. We can construct complex flexibility using the basic unit of options.

In financial terms, a typical example of an option is a "call option" that gives the holder the right to buy an asset for a specified exercise price within or at a specified time. The holder of the call option will exercise this right only if the value of the asset rises above this price, but not otherwise. The key property of an option is the asymmetry of the payoff, an option holder can avoid downside risks and limit the loss to the price of getting the option, while being able to take advantage of the upside opportunities. Usually, there is a price or cost to obtain an "option".

"Real options" is the term used to emphasize the options that involve projects or physical objects, as opposed to purely financial agreements, as in the case, for instance, of stock options. For example, they may be associated with the valuation of an offshore oilfield, the development of a new drug, the timing of the construction of a highway, or the design of a satellite communications system. Since Myers (1984) coined the term of "real options", researchers have been developing a variety of means to evaluate real options.

Real options "in" projects

Real options can be categorized as those that are either "on" or "in" projects (de Neufville, 2002). Real options "on" projects are financial options taken on technical things, treating technology itself as a "black box". Most studies of real options are for those "on" projects, for example, a real investment opportunity in a gold mine (Luenberger, 1998) or investment in capacity expansion for a petroleum chemical company (Amram and Kulatilaka, 1999).

Real options "in" projects are created by changing the actual design of the technical system. The design of the original bridge over the Tagus River at Lisbon provides a good example of a real option "in" a project. The original designers built the bridge stronger than originally needed, so that it could carry a second level, in case that was ever desired. The second level of bridge was an option "in" the bridge design, and the Portuguese government exercised this option in the mid 1990s, building on a second deck for a suburban railroad line (Gesner and Jardim, 1998).

De Neufville et al (2005) developed an example of designing real options into a multilevel parking garage. This case concerns a parking garage in a region that is growing as population expands. Economic analysis recognizes that actual demand is uncertain, given the long time horizon. If the owners design a big parking garage, it is possible that the demand will be smaller and the cost of a big garage cannot be recovered. However, if the owners design a small parking garage, they may miss important revenues if the demand grows rapidly. To deal with this dilemma, the owners can design a real option into the design by strengthening the footings and columns of the original building – with an upfront cost of such extra work -so that they can add additional levels of parking easily. The results of the real options analysis show the flexibility provided by building small initially with the option to expand has several advantages. It

- increases the expected value of the project;
- Reduces the maximum possible loss;
- Increases the maximum possible and the expected gain
- While reducing the initial capital costs.

Note the difference between real options "in" projects and the engineering concept of "redundancy". Both real options "in" projects and redundancy refer to the idea that some components should not have been designed if the design were optimized given the assumption that things are not going to change. Redundancy refers to more than enough design elements to serve the same function (such as duplicate on-board navigation computers), while real options "in" projects may not serve the same functions as some currently existing components -- indeed they may serve a new function, such as supporting a rail line across the highway bridge.

Difficulties facing real options "in" projects

There are two key difficulties facing the analyses of real options "in" projects. The first is that while financial options are well-defined contracts and real options "on" projects are easy to construct via different financial arrangements, it is much harder to identify real options "in" projects where there are myriads of design variables and parameters. The second difficulty is that real options "in" projects often exhibit complex path-dependency/interdependency that standard options theory does not deal with. Real options "in" projects are different and need an appropriate analysis framework - existing options analysis has to adapt to the special features of real options "in" projects. This paper addresses how to deal with the first difficulty of identification of real options "in" projects, while the authors had a paper on analysis of complex path-dependent/interdependent real options "in" projects (2004).

Identification of real options "in" projects

The options identification process consists of two parts: a screening and a simulation model.

Screening model

The options "in" projects for an engineering system are complex. It is not obvious how to decide their exercise price, expiration day, current price, or even to identify the options themselves. An engineering system involves a great many choices about the date to build, capacity, and location, etc. The question is: which options are most important and justify the resources needed for further study?

The screening model is set up to focus on the most important variables and interesting real options (flexibility). It is a simplified, conceptual, low-fidelity model for the system. Without losing the most important features, it can be easily run many times to explore an issue, while the full, complete, high-fidelity model is hard to establish and costly to run. From another perspective, the screening model is the first step of a process to reduce the design space of the system, by "screening out" uninteresting designs. Both the design space and the possibility for future realization of exogenous uncertain factors is extremely big. Therefore, we cut the design space smaller and smaller in steps, rather than using a holistic model to accomplish all the results in one run. The screening model is the first cut that focuses on the important issues and is low fidelity in nature. In this sense it is like looking at the system from a height of 30,000 feet for an overview. The screening model may be simplified in a number of ways. If an aspect simplified is important in nature, we should design follow-on models to the screening model to study that aspect in depth. Note when feedback exists in the system, the screening model has to carefully take care of the feedback; otherwise, it may produce misleading or erroneous conclusions.

Specifically, a screening model can be a linear (or nonlinear) programming model:

Max: $$\sum_j (\beta_j Y_j - c_j Y_j)$$ Equation 1

s.t. $$\mathbf{TY} \geq \mathbf{t}$$ Equation 2

$$\mathbf{EY} \geq \mathbf{e}$$ Equation 3

Y_j are the design parameters. The objective function (Equation 1) calculates the net benefit, or the difference between the benefits and costs, where β_j and c_j are the benefit and cost coefficients. Usually we measure benefits in money terms, though sometimes we do so in other measures, e.g. species saved, people employed, etc. Constraints (Equation 2 and 3) represent technical and economic limits on the engineering systems, respectively.

Any parameter in the formulation could be uncertain. There are economic uncertainties in $\mathbf{E}$, $\mathbf{e}$, β_j, or c_j and technical uncertainties in $\mathbf{T}$ or $\mathbf{t}$. After identifying the key economic uncertainties, we can use them to build up the real options analysis.

To identify the elements of the system that seem most promising for options, we execute a form of sensitivity analysis. The procedure is as follows:

- run the screening model using a range of values for key underlying uncertain parameters, such as the price of electricity;
- compare the resulting sets of projects that constitute optimal designs for each set of parameters used;
- notice that the design elements that vary across the sets are those that may be good real options; and

- conversely, the design elements that are included for all sets, that are insensitive to uncertainty, or design elements where settings are always constant do not present interesting real options.

The options identified by this process have two sources of flexibility value:

- Value of timing. Some part of the project may be deferred. These represent timing options. Its implementation depends on the realized uncertain variables. It can catch upside of the uncertainties by implementation, and avoid downside of the uncertainties by holding implementation. Such timing options have significant value by themselves.
- Value of flexible design. Some part of the project may present distinct designs given various realization of uncertainties, compared to the timing options whose design are the same whenever they are built.

An option can contain one or both sources of flexibility value.

Simulation model

The simulation model tests several candidate designs from runs of the screening model. It is a high fidelity model. Its main purpose is to examine, under technical and economic uncertainties, the robustness and reliability of the designs, as well as their expected benefits. Such extensive testing is hard to do using the screening model. After using the simulation model, we find a most satisfactory configuration with design parameters $(\overline{Y_1}, \overline{Y_2}, \ldots, \overline{Y_j})$ in preparation for the options analysis.

Case example – identification of real options in water resources systems

The case example concerns the development of a river basin involving decisions to build dams and hydropower stations in China. The developmental objective is mainly hydro-electricity production. Irrigation and other considerations are secondary because the river basin is in a remote and barren place.

The screening model is the first cut of the design space that focuses on the important issues and low fidelity in nature. It may be simplified in many ways. In the river basin development case example, we simplified the problem by regarding it as a deterministic problem, taking out the stochasticity of the water flow and electricity price. Another simplification is that we regard all the projects are built together at once, neglecting the fact that the projects have to be built in a sequence over a long period of time. In other words, the screening model looks at steady state conditions. With such simplifications, we can focus our attention on identifying the most interesting flexibility, and leave the scrutiny of the aspects in the following models and studies. The resulted screening model is a non-linear programming model.

After the screening model is established, some detailed consideration and care should be taken when applying it. What uncertain parameters should be examined? What levels of the uncertain variables should be placed into the screening model? After establishing the screening model, we suggest the following steps to use the screening model systematically to search for the interesting real options:

Step 1. List uncertain variables. These could be exogenous or endogenous, such as market uncertainty, cost uncertainty, productivity uncertainty, technological uncertainty, etc.

Step 2. Find out the standard deviations or volatilities for the uncertain variables. This can be computed from historical data, implied by experts' estimation, or estimated from comparable projects.

Step 3. Perform sensitivity analysis on the uncertain variables to pick out the several most important uncertain variables for further analysis. A tornado diagram is a useful tool for such sensitivity analysis.

Step 4. List different levels of the important uncertain variable as inputs for the established screening model to identify where the most interesting real options are.

Step 1. The uncertain variables for the river basin development include the price of electricity, fixed cost of reservoir, variable cost of reservoir, variable cost of power plant, and water flow, etc. For the purpose of illustration, we pick out three important uncertain variables for further scrutiny: electricity price, fixed cost of reservoir, and variable water flow. This is only for illustration purposes, and real studies should examine more uncertain variables - the most important uncertain variables may in fact be beyond normal expectation or intuition.

Step 2. In this case, the volatility of electricity price was derived from experts' estimation. The author interviewed two Chinese experts on China energy market to get their pessimistic, most likely, and optimistic estimate of the electricity price for 3 years later. The experts reached the optimistic price estimate of 0.315 RMB/kWh (RMB is Chinese currency) and pessimistic estimation of 0.18 RMB/kWh both with 95% confidence, which corresponds to a volatility of 6.96% per year (for details see Wang 2003, pp.101). The standard deviation of the construction cost was estimated from the standard deviation for cost of megaprojects (Flyvbjerg, et al., 2003, pp. 16). The standard deviation is 39%. The standard deviations of water flow were calculated from historical data.

Step 3. Understanding the volatility or standard deviation of the three uncertain parameters, it is possible to calculate the sensitivity of the objective function to them. A tornado diagram can express the change of net benefit due to 1 standard deviation/volatility change of each important uncertain variables, with other uncertain variables kept at the expected value. To do so, we just change one variable a time (with 1 standard deviation or volatility) in the screening model, run the optimization and get the corresponding optimal net benefit to draw the tornado diagram. The resulting tornado diagram is as Figure 1. Note the skewness for fixed cost for reservoir and water flow, that is, the change of net benefit is asymmetric if the uncertain variables change positively or negatively. For the fixed cost for reservoir, if cost is about positive one standard deviation, site 3 is not in the solution, and the loss is limited; while if cost is negative one standard deviation, site 3 is in the solution, and may generate more electricity revenue. For water flow, the projects are not going to benefit much from overflow and may have to spill overflow water, while the projects have to take the whole loss if water is less than enough.

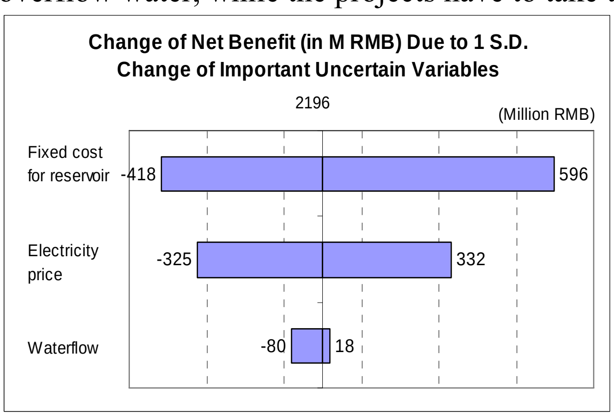

Figure 1 Tornado chart for screening model

The tornado diagram indicates which uncertainties most effect the objective. In this case., Figure 2 indicates that the uncertainties on fixed cost of reservoir and electricity price are most important. For simplicity, this example case study focuses only on the uncertainty of electricity, however. This is enough to illustrate the approach. In a realistic application, the analysis should at least be based on both uncertainties of electricity price and fixed cost for reservoir jointly, if there are no other important uncertain variables overlooked.

Step 4. Although the current price of electricity is 0.25 RMB/KWH, but we study the conditions when the electricity price is 0.10, 0.13, 0.16, 0.19, 022, 0.28, 0.31 RMB/KWH. The levels cover most of the range of the experts' pessimistic (0.18 RMB/KWH) to optimistic estimate (0.315 RMB/KMB). To be conservative, we also screen at very low electricity prices as a stress test to see what could happen in the case worse than we would imagine.

Table 1: Results from the screening mode

Case	Electricity Price (RMB/KWH)	H_1 (MW)	V_1 ($10^6 m^3$)	H_2 (MW)	V_2 ($10^6 m^3$)	H_3 (MW)	V_3 ($10^6 m^3$)	Optimal Value (10^6RMB)
1	0.09	0	0	0	0	0	0	0
2	0.12	3600	9600	1700	25	0	0	367
3	0.15	3600	9600	1700	25	0	0	796
4	0.18	3600	9600	1700	25	1564	6593	853
5	0.22	3600	9600	1700	25	1723	9593	1607
6	0.25	3600	9600	1700	25	1946	12242	2196
7	0.28	3600	9600	1700	25	1966	12500	2796
8	0.31	3600	9600	1700	25	1966	12500	3396

Given the 8 levels of electricity price, we get 8 preliminary configurations of the projects. The optimization model is written in GAMS©, and the results are as in Table 1. *Hs* represents the capacity of power plant at site *s*; *Vs* represents the capacity of reservoir at site *s*. "Optimal value" represents the maximum net benefit calculated by the objective function. Note that for case 1, no projects are built; for cases 2 and 3, site 3 is screened out. In a real application considering many more sites, there may be a great number of sites entered the screening models and most of them are screened out. We find that the designs of (H_1 = 3600 MW, V_1 = 9.6 X 10^9 m^3) and (H_2 = 1700 MW, V_2 = 2.5 X 10^7 m^3) are robust with regard to the uncertainty of the electricity price (The only case that these designs are not optimal is when the price of electricity is extremely low - where we do the stress test and is out of the range of experts' estimation). But for the project at site 3, the optimal design changes when the price of electricity changes, and this is the place on which we should focus designing flexibility.

Each design for site 1, 2 and 3 represents an option, though the sources of them are subtly different: all options present timing feature, but only option at site 3 has flexible design feature where we consider different reservoir capacity and power plant capacity design. See Table 2. Although the features of options have been understood, the final options specification will not be reached until the test of simulation model.

Table 2 Sources of options value for designs

	Sources of option value	
	Value of timing	Value of flexible design
Design at site 1	Yes	No
Design at site 2	Yes	No
Design at site 3	Yes	Yes

Simulation model to test other considerations

In standard water resources planning, the simulation model involves many years of simulated stochastic variation of the water flows, generated on the basis of historical records. This process leads to a refinement of the designs identified by the screening model. For the analysis of real options "in" water resources systems, it is appropriate to modify the standard simulation by combining the effects of stochastic variation of hydrologic and economic uncertain parameters.

If the time series of the water flow consisted of the seasonal means repeating themselves year after year (no shortages with regard to the design obtained by the screening model) and the price of electricity were not changing, the simulation model should provide the same results as the screening model. But the natural variability of water flow and electricity price will make the result (net benefit) of each run different, and the average net benefit is not going to be the same as the result from the screening model. The simulated results should be lower because the designs are not going to benefit from excess water when water is more than the reservoir can store. Thus occasional high levels of water do not provide compensation for lost revenues by occasional low levels of water. Due to these uncertainties, the economies of scale seemingly apparent under deterministic schemes are reduced.

Satisfying the requirements of various technical considerations such as robustness and reliability, the design with the highest expected benefit from the simulation is that corresponding to the electricity price of 0.22 RMB/KWH (Case 5). Note due to the uncertainties in electricity price and water flows, it is not the design corresponding to current electricity of 0.25 RMB/KWH. So the timing options for site 1 and 2 are (H_1 = 3600 MW, V_1 = 9.6 X 10^9 m^3) and (H_2 = 1700 MW, V_2 = 2.5 X 10^7 m^3), we have the right to build a project as the specifications, but we do not have the obligation to build them and have the room to observe what happens and decide where to build a project. The option for site 3 contains both timing option and variable design option. We choose 3 design centered Case 5, or (H_3 = 1564 MW, V_3 = 6.93 X 10^9 m^3), (H_3 = 1723 MW, V_3 = 9.593 X 10^9 m^3), or (H_3 = 1946 MW, V_3 = 12.242 X 10^9 m^3). Each design is an option, in that we have the right but not obligation to exercise the option, and the three options are mutually exclusive - only one can be built. Table 3 summarizes these options. As is normally the case, designers have a portfolio of options.

Table 3 Portfolio of options for water resources case

	Design specifications	Exercise time
Option at Site 1	H_1 = 3600 MW, V_1 = 9.6 X 10^9 m^3	Any time
Option at Site 2	H_2 = 1700 MW, V_2 = 2.5 X 10^7 m^3	Any time
Option at Site 3	One of $\left\{ \begin{array}{l} H_3 = 1564 \text{ MW}, V_3 = 6.93 \text{ X } 10^9 \text{ m}^3 \\ H_3 = 1723 \text{ MW}, V_3 = 9.593 \text{ X } 10^9 \text{ m}^3 \\ H_3 = 1946 \text{ MW}, V_3 = 12.242 \text{ X } 10^9 \text{ m}^3 \end{array} \right.$	Any time

General applicability of options identification in other projects

The framework proposed is generally applicable to designing flexibility (real options) into various projects. This next example shows the application of the framework to another case example, by way of illustrating the generality of the approach. This case example builds on the analysis of a satellite communications system similar to the Iridium system (de Weck et al, 2004). In 1991, forecasts for the satellite cellular phone market expected up to 3 million subscribers by the year 2000. Initiatives like Iridium and Globalstar were encouraged by the absence of common terrestrial cellular phone standards and slow development of cellular networks at that time. Iridium was designed according to the forecast of 3 million subscribers. However, the rapid success of terrestrial cellular networks and the inconvenient features and high costs of satellite cellular phones soon appeared to doom the two ventures. Iridium only aroused the interest of 50K initial subscribers and filed for bankruptcy in August 1999. Globalstar went bankrupt in February 2002.

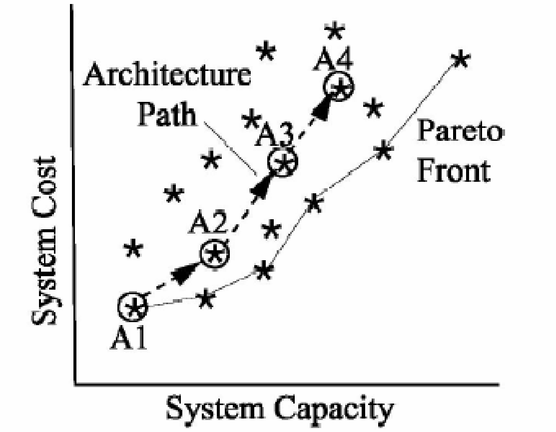

Figure 2 Example of a path in trade space [Source: de Weck et al. 2004]

Chaize (2003) and de Weck et al. (2004) developed a design space for the satellite communications system similar to that of Iridium system by optimization and numerical experiment. The design space is a enumeration of points of system cost and system capacity given various designs based on selection of parameters of orbital altitude, minimum elevation angle, transmit power, antenna diameter, an the use of inter satellite links. After plotting around 1,500 such points, it is possible to define the Pareto Frontier for design as the locus of the best designs – those providing capacity at least life-time cost. Based on the demand growth scenario, possible staged development paths can be recognized. Note that a path is not on the Pareto frontier (refer to Figure 2), because the staged design sacrifices some benefits of economies of scale, though staged development may prove better in an uncertain environment as shown in the next section.

A major flexibility in the satellite case arises from the possibility of repositioning satellites and launching additional satellite to increase the capacity of the system. A smaller system with fewer satellites with a higher orbit – and thus smaller capacity -- can be established first. One possible real option is to carry extra fuel on each satellite. When demand proves big, the satellites can move to lower orbits. With additional satellites launched to lower orbits, a bigger system is accomplished to serve the big demand. There is cost to acquire such real options – the cost of designing larger tanks and launching extra fuel. The model developed by de Weck et al (2004) is a screening model in effect.

A design with an evolutionary configuration that had the capability to expand capacity, could have both increased the expected value of the system by around 25%, as well as cut the maximum losses by about 60% (de Weck et al, 2004). Decision makers have the right to exercise the options, but not the obligation – they can leave the extra fuel on board.

There may be some possible complications to applying this framework to a specific engineering system. For example, if the the optimization screening model is not suitable for an engineering system, an alternative approach may be needed. Colleagues at MIT are indeed now working on such possibilities. Alternatively, iIf there are few robust design parameters from the screening model run, that is, if most parameters vary greatly under different conditions, it may be necessary to calculate the sensitivity of the design parameters with regard to the value of the project, pick several most important parameters that affect the value of project greatly, and study carefully the flexibility corresponding to those parameters.

Conclusions

Designing flexibility into projects increases the value of projects significantly: it reduces the maximum possible loss, and increases the maximum possible and the expected gains.

The options identification discovers the design elements most likely to provide worthwhile flexibility. For real options “in” projects, in comparison to those “on” projects, the identification of options is not trivial. As there are often too many possible options for systems designers to consider, they need a way to identify the most valuable options for further consideration. One approach to doing this is through using a screening model. This is a simplified, conceptual, low-fidelity model for the system that conceptualizes its most important issues. As it can be easily run many times, it is used to extensively test designs under dynamic conditions for robustness and reliability; and to validate and improve the details of the preliminary design and set of possible options. Once the screening model has identified plausible options, a detailed simulation model can validate and refine the options.

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Bibliography

Dr. Tao Wang received his PhD degree from MIT in June 2005. His research area is on real options and systems design, especially on real options “in” projects created by changing the physical design of the technical system. He now focuses on interest rate options at Morgan Stanley.

Dr. Richard de Neufville is Professor of Engineering Systems at MIT. He has written 5 textbooks on engineering systems analysis, and received many awards for this work, including the NATO Systems Science Prize. He is now working on the use of flexibility and real options in the design of major civilian and military systems. He was an Army Airborne Ranger and a White House Fellow for the Secretary of Defence.