Am. Soc. of Civil Engineers, Journal of Infrastructure Systems, Vol. 12, no. 3, pp. 107 -111, 2006

Real Options by Spreadsheet:
Parking Garage Case Example

Richard de Neufville, L.M. ASCE, Stefan Scholtes, and Tao Wang

Abstract

This technical note shows how designers of infrastructure systems can evaluate flexibility in engineering systems in fairly simple ways. Specifically, it illustrates a spreadsheet approach to valuing “real options” in a project. The model avoids complex financial procedures, which are both inappropriate for most design issues and constitute barriers to understanding and thus achieving the substantial improvement in performance that real options enable. The spreadsheet approach uses standard procedures; is based on data available in practice; and provides graphics that explain the results intuitively. It should thus be readily accessible to practicing professionals responsible for engineering design and management. A practical application to the design of a parking garage demonstrates the ease of use and presentation of results of this approach.

CE Database Subject Headings: design, flexibility, uncertainty analysis, real options, facility expansion, spreadsheets, project evaluation, parking facilities.--

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Valuing Real Options by Spreadsheet: Parking Garage Case Example

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The Opportunity

Designers of infrastructure systems know that many of their forecasts are "always" wrong. Market forces and volatility of public desires generate loads for infrastructure services that are frequently far different from those originally anticipated. These demands may be more or less than projected. Highways that are full the day they open are as much a part of our experience as under used facilities such as the English Channel Tunnel or the Tokyo Bay Bridge. Many accounts describe this reality, such as Flyvbjerg et al (2003) and de Neufville and Odoni (2003).

In this context, it often might be cost-effective to stage the development of infrastructure, to bring it into service when and where it is needed. Staging avoids the development of unnecessary capacity. It also defers expenses until they are needed, which can reduce the present value cost of the system considerably. Moreover, when the implementation of later stages is deferred until they are needed, the design of the infrastructure can accommodate the latest technology and cater more precisely to the actual needs. For example, because the original design of the bridge across the mouth of the Tagus included the flexibility to accommodate railroad traffic, the later designers were able to provide efficient connections to the urban rail system designed and implemented many years afterwards (Gesner and Jardim, 1998).

Being able to do the right thing at the right time can lead to spectacular improvements in the expected present value of major infrastructure systems. Thus, de Weck et al (2004)

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demonstrated that improvements on the order of 30% were possible through the proper staging of the deployment of communication satellites. This is the kind of opportunity available if we manage to design and implement flexible infrastructure systems.

The Problems

Two problems are barriers to planning and designing infrastructure systems that can deployed as needed. The first is that flexibility costs; the second that designers do not yet have acceptable means to value and thus justify this expense. That flexibility costs is obvious. To endow the Tagus Bridge with the capacity for a second deck to carry trains should this ever be desired, the Portuguese government initially had to spend considerably more for steel, construction, access, etc. How can designers justify such costs analytically?

The way to justify flexibility in design is through some form of “real options analysis”. A “real option” embodies flexibility in the development of a project. It represents a “right, but not an obligation” to take some course of action – such as the construction of rail lines over the Tagus Bridge -- that may be advisable either if there is some unfortunate turn of events or some new opportunities. A “real option” thus represents either a form of insurance or a means to take advantage of a favorable situation. “Real options analysis” is the body of techniques used to value flexibility in the deployment of technical systems, such as infrastructure.

The concept of real options originated in the field of finance (Myers, 1984). Its theory has used financial models based on the assumption that the options concerned assets (such as stocks or commodities) traded in markets. Since the early 1990s, numerous authors have extended this analysis based on financial options to engineering systems (for example Dixit and Pindyck, 1994; Trigeorgis, 1996; Amran and Kulatilaka, 1999; Copeland and Antikarov, 2001).

Theorists have more recently proposed the application of real options analysis to the design of infrastructure systems. Leviakangas and Lahesmaa (2002) discuss applications to toll roads; and

Ford et al. (2002) to strategic planning. Ho and Liu (2003) present a method for evaluating investments in construction technology; Zhao and Zheng (2003) apply an alternative approach to parking garages; Zhao et al (2004) extend this work to highway development.

However, real options analysis has not been widely used in engineering practice. The probable reason is that financially-based approaches are not acceptable in practice. These procedures require an understanding of financial theory and advanced mathematical techniques (such as trinomial lattice and stochastic dynamic programming, Wang and de Neufville, 2004). They also call for statistical data such as the volatility of the asset that, while meaningful in financial markets, have no obvious parallels in engineering practice. Thus, even when practitioners are skilled in the use of the financial techniques for evaluating options, the results they produce are based on assumptions that are difficult to explain. Using techniques based on finance theory, it will thus be difficult to value flexibility and justify it to the senior engineers and managers who are ultimately responsible for approving the configuration and design of infrastructure systems.

However, simple spreadsheet analyses -- readily accessible to designers -- can be used to estimate the value of real options in engineering systems. This approach has three advantages compared to alternative procedures based on financial mathematics. It:

1. uses standard, readily available spreadsheet procedures;
2. is based on data available in practice; and
3. provides graphics that explain the results intuitively.

The case study of the design of a multi-level parking garage illustrates these points.

Spreadsheet Analysis

This valuation of flexibility is based on standard discounted cash flow (DCF) analysis engineers and managers regularly use to evaluate projects (see Riggs and West, 1986; de Neufville, 1990; White et al, 1998; DeGarmo et al, 2000). The process discounts future revenues and expenses to place them on a comparable basis. The sum of these discounted cash flows is the net present value (NPV). Computer-based spreadsheets, such as Excel®, provide the needed tools.

Estimating the value of real options using spreadsheets is simple and easy to do. The designer places the basic data in the spreadsheet and then can do the calculations minutes. Readers can use the authors' simple model at http://ardent.mit.edu/real_options or commercial software such as Crystal Ball ® and @Risk ® .

Real options analysis using spreadsheets involves 3 steps:

1. Set up the spreadsheet representing the most likely projections of future costs and revenues of the project, and calculate its standard engineering economic value. The design that maximizes the NPV is the base case against which flexible solutions are compared, so as to derive the value of these alternative designs.
2. Explore the implications of uncertainty by simulating possible scenarios. Each scenario leads to a different NPV, and the collection of scenarios provides both an "expected net present value" (ENPV) and the distribution of possible outcomes for a project. These are usefully plotted as cumulative distribution functions that document the Value at Risk (VaR), that is, the probabilities that worse cases could occur. This documentation motivates the search for the flexibility, for the real options, that will enable the managers of the infrastructure to avoid these losses.
3. Analyze the effects of various ways to provide flexibility by changing the costs and revenues to reflect these design alternatives. The difference between the resulting best ENPV and that of the base case is the value of flexibility. Moreover, the VaR curve for the flexible design intuitively explains how flexibility allows system operators to avoid downside losses and take advantage of upside opportunities. This information can be a key factor in decisions about the design of major projects.

The spreadsheet approach to real options analysis thus provides solutions that senior decision-makers can appreciate and accept. It builds upon tools they are familiar with, uses the data they provide, and demonstrates graphically the sources of value. The case of an actual development illustrates the point.

Case Study

The Case: The spreadsheet approach was applied to the design of a parking garage, inspired and extrapolated from the Bluewater development in England (http://www.bluewater.co.uk/). . This example shows the ease of use and transparency of the approach, particularly when contrasted with financial methods for dealing with the same issue (see Zhao and Tseng, 2003).

The case deals with a multi-level car park for a commercial center in a region that is growing as population expands. The basic data are that:

- The deterministic point forecast is that demand on opening day is for 750 spaces, and rises exponentially at the rate of 750 spaces per decade;
- Average annual revenue for each space used is $10,000, and the average annual operating cost for each space available (often more than the spaces used) is $2,000;
- The lease of the land costs $3.6 Million annually;
- The construction will cost $16,000 per space for pre-cast construction, with a 10% increase for every level above the ground level;
- The site is large enough to accommodate 200 cars per level; and
- The discount rate is taken to be 12%.

Additionally, economic analysis needs to recognize that actual demand is uncertain, given the long time horizon. The case assumes that future demand could be 50% off the projection, either way, and that the annual volatility for growth is 15% of the long-term average.

Flexibility: The owners can design the footings and columns of the original building so that they can add additional levels of parking easily, as was the case for the Bluewater development. The case assumes that doing so adds 5% to the total initial construction cost. This premium is the price to get the real option for future expansion, the right but not the obligation to do so.

Step 1: Table 1 illustrates the basic spreadsheet for calculating the NPV of the parking garage, assuming that the demand for spaces grows as projected. Note that the project cannot benefit from addition demand when it exceeds the capacity of the facility.

The designer can use the spreadsheet to calculate the NPV for any number of levels for the car park (Figure 1) and thus determine the size that is maximizes NPV. The optimal design for this base case, that unrealistically assumes that demand is known in advance, is to build 6 floors. Its apparent NPV is $6.24 million. This estimate is however wrong: actual demand will vary from the deterministic forecast, so that the ENPV of this design will also be different, as Step 2 documents.

Step 2: Recognizes the uncertainty in the forecast demand by simulating possible scenarios, S. This example analysis ran 2000 scenarios, which took about 1 minute on a standard PC. Each scenario implies a different NPV. The set of scenarios thus represents the probability distribution of the NPV that might occur. As Figure 1 indicates, the actual expected NPV for the deterministic design is less than that estimated from a deterministic analysis. It is only $2.87 million. In fact, the smaller 5-level design provides greater expected NPV ($ 2.94 million) since it lessens the possibility of big losses from overbuilding capacity that might not be used.

The analysis considering uncertainty provides useful insights that should motivate designers and decision-makers to use flexibility. It shows that:

- Uncertainty can lead to asymmetric returns. In this case, although the case assumes that the chance of higher and lower demands are equal, the upside value of the project is limited (because the fixed capacity cannot take advantage of higher demands) while the downside risks are substantial and can lead to great losses.

- The actual expected value of a project P over all the scenarios in general is not equal to the value of a project for an average scenario, as Figure 1 indicates. This is the "Flaw of Averages" or Jensen's Inequality (Savage, 2000):

  $$EV\ P(S) \neq P\ [EV(S)]$$

- The cumulative distribution gives the Value at Risk (VaR). It shows the probability that an NPV might be less or equal to a threshold. Thus Figure 2 shows that there is about 10% chance that the losses from the 5-level parking garage would exceed $4 million.

Step 3: Explores ways to limit the downside risk and take advantage of upside potential. For example, designers can reduce losses by creating smaller designs that lower the chance that demand will not fill the facility. In this case, the smaller design eliminates the chance of really big losses, but at the cost of never making any substantial profit. Thus, as is frequently the case, simply providing good insurance against losses is not sufficient to make a project attractive.

Designers can to take advantage of possible growth by building expansion flexibility into the design. As done in the parking structures for the Bluewater development, this case considered the possibility of making the columns big enough to support additional levels, should demand justify expansion of the parking garage in later years. Table 2 shows the spreadsheet to explore this expansion option, with appropriate modifications in bold type. It incorporates additional rows for "Extra capacity", and "Expansion cost". For this case, the decision to construct an extra floor or 200 spaces was made if the capacity was less than the demand for two consecutive years. Other criteria and rules could be programmed in.

The graphical interpretation is that the designer shifts the VaR curve to the right by reducing the extent of the lower tail into losses, and pushing the upper tail into gains. Figure 3 shows the joint VaR of building small with the option to expand if demand is favorable. The initial design of only 4 levels greatly decreases the maximum loss (from 24.68 to 12.62 million). The capability to add capacity increases both the maximum value of the project (from 13.78 to 14.80 million) and its expected value. The estimated value of the options embedded in the flexible design is the difference between the expected value with the options ($5.12 million) and the expected value of the base case design defined in the standard deterministic way (2.87 million), that is $2.25 million in this case.

The flexibility provided by building small initially with the option to expand has several advantages beyond increasing the expected value of the project. The spreadsheet approach to the real options analysis generates the data that bring out these features, as the financial approaches do not. Table 4 presents this information and provides a multi-faceted analysis and justification of the flexible approach to design. In this case the analysis documents that the flexible design of the multi-level garage:

- Reduces the maximum possible loss, that is the Value at Risk;
- Increases the maximum possible and the expected gain;
- While maintaining the initial investment costs low.

Conclusion

The case study shows that a spreadsheet model for real options analysis is easy to use and provides insight into the way that flexibility in design minimizes exposure to risk and maximizes the potential for gain under favorable circumstances. Compared to alternative approaches that require advanced mathematics and financial concepts, and that focus narrowly on the expected value of an option and ignore the ways options change the distribution of outcomes, the spreadsheet approach is both much easier to use and more informative. Because the spreadsheet model for the valuation of real options rests on readily available tools and data, practicing engineers and managers should also find this approach accessible and useful.

Acknowledgements

The authors appreciate the cooperation of senior staff of Laing O'Rourke (UK) who worked with the lead authors on the application of the spreadsheet model, and its validation through practical examples, during the Cambridge-MIT Institute Workshop on Real Options in May 2004. They are also grateful for the reviewers and editor for their advice on the presentation.

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Table 1. Spreadsheet for Design with Deterministic Point Forecast of Demand (Case of 6 level garage)

Category	Type	Units	Year 0	1	2	3	…	20
Demand		Spaces		750	893	1,015	…	1,696
Capacity	Initial			1,200	1,200	1,200		1,200
Revenue		$ millions		7.50	8.93	10.15		12.00
Cost	Initial		22.74					
	Annual		3.60	6.00	6.00	6.00		6.00
Cash Flow	Actual		- 26.34	1.50	2.93	4.15		6.00
NPV			**6.24**					

Table 2 Spreadsheet for Design with One Scenario of Demand and Option to Expand (Case of 4 level garage)

Category	Type	Units	Year					
			0	1	2	3	…	20
Demand		Spaces		1055	1141	1234	…	1598
Capacity	Initial			800	800	**1,000**		**1,800**
	Added				**200**	**200**		
Revenue		$ millions		8.00	8.00	10.00		15.98
Cost	Initial		14.48					
	Later				**4.26**	**4.68**		
	Annual		3.60	5.20	5.20	**5.60**		**7.20**
Cash Flow	Actual		-18.08	2.80	-1.46	-0.28		8.78
NPV			**7.57**					

Table 3 Comparison of 3 Steps of Analysis

Perspective	Step of Analysis	Simulation Used?	Has Option?	Design Levels	ENPV $, millions
Deterministic	1	No	No	6	2.87
Recognizing Uncertainty	2	Yes	No	5	2.94
Incorporating Flexibility	3	Yes	Yes	4, with strong columns	5.12

Table 4 Performance Improvements achieved with Flexible Design

(Maxima and Minima of simulation taken at 0.05 and 99.5 percentile)

Metric $, millions	Design		Comparison
	No Flexibility	Flexible	
Initial Investment	22.74	14.48	Flexibility Better
Expected NPV	2.87	5.12	Flexibility Better
Minimum NPV	-24.68	-12.62	Flexibility Better
Maximum NPV	13.78	14.80	Flexibility Better

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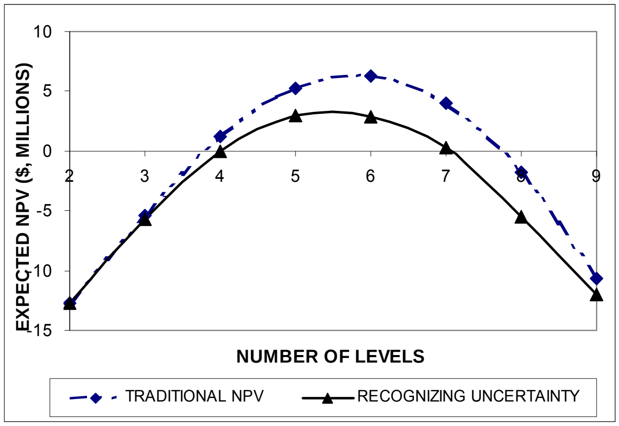

Figure 1. Expected Net Present Value for Designs with Different Number of Levels

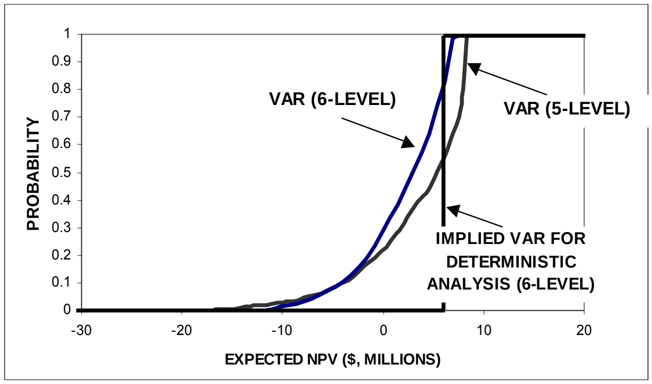

Figure 2. Value at Risk for 6 level design recognizing demand uncertainty, compared to deterministic estimate

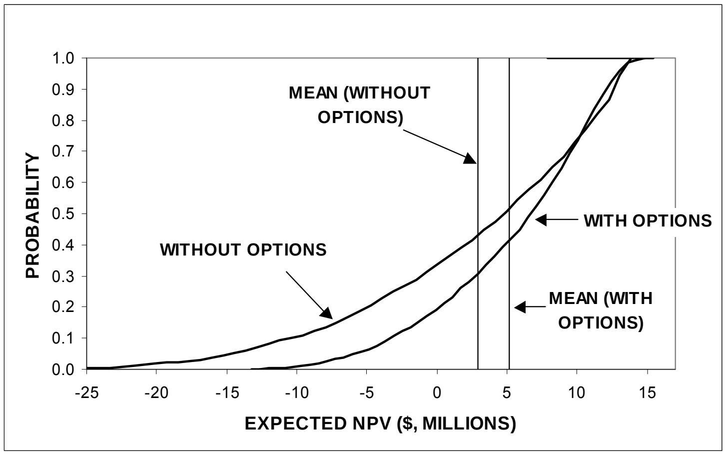

Figure 3. Option to Expand adds significant value and improves profile of Value at Risk