

## USING REAL OPTIONS TO INCREASE THE VALUE OF INTELLIGENT TRANSPORTATION SYSTEMS

Richard de Neufville<sup>1</sup>, Kenichi Hodota,<sup>2</sup> Joseph Sussman<sup>1</sup>, and Stefan Scholtes<sup>3</sup>

### ABSTRACT

This paper presents a practical approach to calculating how design flexibility, that is “real options”, in systems can increase the value of these enterprises. A flexible approach to the deployment of infrastructure systems enables owners to manage the development of these facilities to increase expected value. Real options in the system make the system adaptable to future patterns of technological innovation and changes in stakeholder needs. With this flexibility, system managers can respond effectively to good opportunities and withdraw from unproductive paths of deployment. This is important because forecasts concerning major infrastructure systems are inherently uncertain: trend-breakers routinely disrupt historical patterns. Real options are especially valuable for innovative, major long-term developments, for which trends hardly exist and forecasts are highly speculative. To illustrate the use and value of real options, the paper presents a case study for the deployment of a particular aspect of intelligent transportation systems: innovative crash avoidance systems that reduce accidents at highway intersections.

Keywords: Real Options, Flexible Design, Infrastructure, Intelligent Transportation Systems, Forecasts, Intersection Collision Avoidance

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### INTRODUCTION

Governments, major corporations and design professionals are increasingly interested in the development of effective procedures for the deployment of complex, large, integrated, long-term infrastructure systems. In part, this is because our communities are now taking on mega projects, such as:

- Networks of high speed rail service on a continental scale, as in Europe;
- Multi billion-dollar networks of oil platforms in the deep ocean, connected to pipelines spanning hundreds of miles; and
- Massive regional projects, such as the British redevelopment of 2 square miles of London<sup>i</sup> for the 2012 Olympics and beyond.

Specifically, there is widespread public and private interest in the deployment of “intelligent transportation systems” (ITS) that embed computer devices in cars and alongside roads to improve roadway safety, efficiency and effectiveness. ITS involve both large costs (although usually smaller than costs of conventional infrastructure) and corresponding economic, environmental, and safety rewards.

The recognition that we collectively have not been very good at getting good value from major projects motivates the concern with efficient procedures for the deployment of engineering systems. As Miller and Lessard (2000) documented, even when large projects are ultimately completed technically, they all too often fail to meet a basic criterion for engineering excellence, which is to provide good value for money. The Channel Tunnel between Britain and France is an example: it provides an attractive service – but has been a financial disaster for the investors. Similarly, the deployment of the Iridium satellite telephone system was a huge technological success – but the US\$4 billion project went bankrupt and was sold for about US\$ 25 million, or about ½ of a percent of its cost (de Weck et al, 2005). We must and should do better.

The great uncertainties associated with long-term major systems are a root cause for unsatisfactory generation of value. Great uncertainty is a signature characteristic of these projects. Over the decade or more that it takes to design and develop the first stage of a system,

there is the possibility of major changes in technology, the economic situation, governmental regulations, the industrial organization as well as the political structure. These trend-breaking events regularly disrupt long-term forecasts. Transportation forecasts in particular have proven to be highly uncertain for all these reasons, as Flyvbjerg and collaborators (2003, 2005) documented.

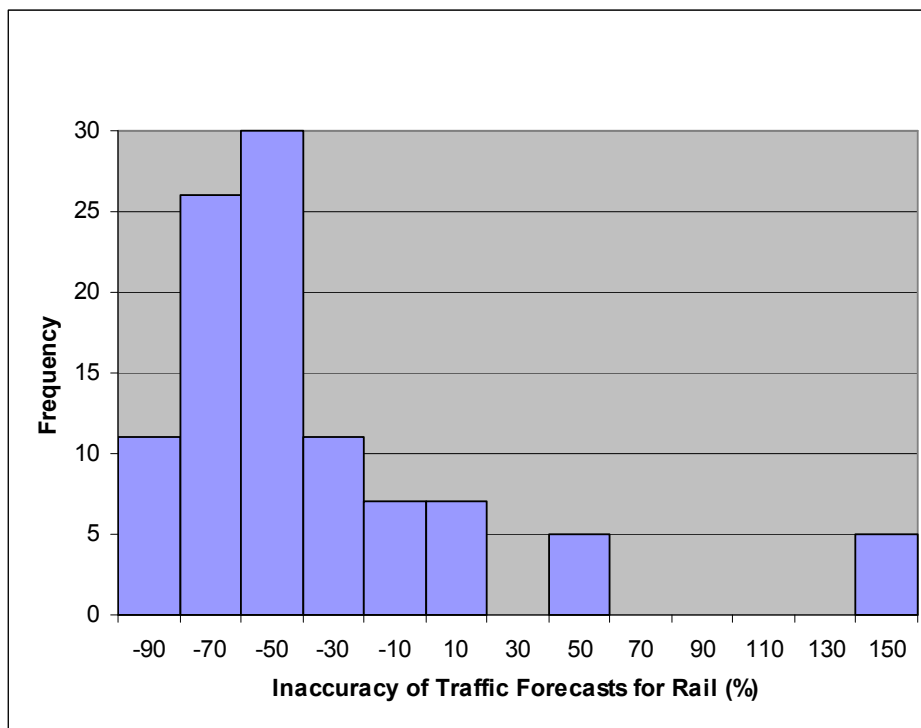
We need a paradigm for planning and design of large-scale engineering systems that deals effectively with the reality that the actual future so regularly differs substantially from the forecast. We need concepts and procedures that enable us to anticipate possible uncertainties, and enable us to deal with them efficiently as they arise. In a word, we need to develop the flexibility to react to events, to take advantage of new opportunities, and to exit from unproductive pathways. We need this because the value that can be expected from a flexible system can be vastly greater than the value derived from a system designed around a specific expected future. As in the financial markets, in which “options” enable companies to protect themselves against risks, designers of large-scale systems need “real options”, that is, the flexibility to alter development trajectories as needed.

Operationally, we need procedures to determine the value of development plans in the context of uncertainty – about both the future environment for the system and our response to these possible scenarios. Conventional methods of valuation, that is the discounted cash flow techniques based upon a point forecast of a single cash flow, are unrealistic when the future is uncertain. The “real options” paradigm, derived from the Nobel-prize winning work that has transformed financial markets, provides a promising approach. It specifically provides means to value flexibility to deal with uncertainty. It thus gives us a way to increase expected value from investments in the deployment of complex, large-scale, long-term infrastructure.

This paper presents “real options analysis” as a way to assess the value of projects facing an uncertain future, and to define development plans that maximize expected value. As a rule, almost by construction, the flexible designs will provide more value, as they systematically avoid bad outcomes, and exploit good opportunities. To demonstrate the approach, the paper applies real options analysis in a case study concerning an anticipated deployment of an intelligent transportation system for avoiding collisions at intersections. As expected, it indicates that a flexible development policy, aggressively pursuing research and development while delaying commitments to widespread roll-outs of devices, maximizes the expected value of ITS for intersection safety.

## ESSENTIAL BACKGROUND -- UNCERTAINTY

The general rule is that forecasts are “always wrong”. Actual events differ from the forecast. Trends vary, and trend-breakers occur routinely. One-year, aggregate national forecasts may be accurate within a percent or so, because circumstances do not generally change rapidly, and because in the aggregate over-forecasts in one sector cancel out under-forecasts elsewhere. Over the decade or more associated with a major project, however, annual errors easily accumulate. Moreover, errors in forecasts for individual projects are not counterbalanced by contrary errors in other projects. As Figure 1 illustrates, 10 to 20-year forecasts for specific transportation systems have routinely proven to be off by 50% or more. Most importantly, the forecasts are not simply biased, in a way that decision-makers could adjust for easily. Empirically, the actual results are widely distributed around the most likely outcome.



**Figure 1: Example data indicating how forecasts for individual major projects are both “always wrong” and widely distributed from original expectations. (Adapted from Flyvbjerg et al, 2003, 2005).**

Trend-breakers are important causes of major discrepancies between forecast and actual outcomes. Trend-breakers are major events that disrupt the patterns that formed the basis for the forecasts. These occur in a variety of dimensions, such as:

- Technical – a disruptive technology may transform markets, just as the development of terrestrial cell phones took away almost all the demand for satellite telephones, taking the Iridium and Globalstar companies by surprise and bankrupting them.
- Economic and Financial – economic booms and busts can both create new trends, as with the dot.com industry in the 1990s, and wipe them out, as the 1990s deflation of land values in Japan undid the rationale for many urban redevelopment programs.
- Regulations -- environmental for instance, such as those that largely stopped the development of nuclear power plants in North America for a generation.
- Industrial -- as when the emergence of low-cost airlines precipitated the bankruptcy of most traditional airlines in the North America.
- Political -- as new US presidents re-orient the long-term objectives of NASA, or the enlargement of the European Community opens new markets for both capital and labor.

Forecasts for innovative systems are particularly uncertain. By definition, almost no trends exist on which to base predictions of their future use or performance. Long-term forecasts for innovative systems are inherently speculative. Considerable uncertainty cannot be avoided for such systems, and in particular for ITS intersection safety, the case study in this paper.

### **Intersection Safety**

ITS should be able to increase safety by reducing collisions between vehicles at intersections. They could do this by either of two major alternative pathways. One focuses on deploying sensors and signaling systems in vehicles and the other places them mostly in the infrastructure at the intersections.

A primary uncertainty for the deployment of ITS technologies for intersection safety thus concerns the rate of market penetration of in-vehicle hardware. If all vehicles had the appropriate hardware, the infrastructure component could be relatively minimalist and most of the safety benefits would be achieved. On the other hand, if market penetration for in-vehicle hardware were low and growing modestly, the public sector would have to deploy more infrastructure hardware at intersections if it wished to achieve safety benefits in the near term. This additional expense would in effect be “wasted” to the extent it would become obsolete when a large fraction of the vehicles on the road are eventually appropriately equipped. However, insofar as the public sector has a strong safety imperative, it may choose to spend money for that additional hardware to achieve the safety benefits more quickly. Thus under some scenarios the cost of ITS

intersection safety would depend significantly on the unknown rate of adoption of in-vehicle safety equipment.

Uncertainties associated with market penetration are not simple to estimate. They depend on many contextual factors. For example, large public sector investments in roadside equipment might suppress demand for in-vehicle hardware – if people believe they are getting the safety benefit without this equipment, they may choose not to buy it. Thus the private manufacturers of in-vehicle safety equipment might oppose some amount of public spending.

A related question concerns the number of intersections endowed with crash-avoidance systems. Clearly the intersections with the highest traffic volumes would be the first target of opportunity, but estimates of the number of intersections that the public sector might be able to equip with collision avoidance hardware must be speculative.

A second area of uncertainty deals with the success of research and development efforts in creating suitable hardware for both infrastructure and vehicles. Exactly when intersection safety hardware might be available in the marketplace is far from certain as are its associated costs. Hence, its deployment has a high degree of temporal risk.

The adoption of in-vehicle hardware is thus fraught with uncertainties of various sorts, depending on complicated interactions between the public and private sector. The public sector would like to be economical in its spending on roadside infrastructure and yet wants safety benefits to accrue quickly. The private sector would like to create an incentive for people to purchase their hardware. The interests of these two sectors will not always align.

### **Using Average Values of Parameters can be Misleading**

The recognition of the great uncertainty in the outcomes of investments in complex, large, integrated, long-term infrastructure systems means that any point estimate of the value of the system is virtually meaningless. The reality is that the value of the system can only be known as some form of distribution. From basic probability theory, it is then true that the probability of any one estimate of value has almost zero chance of occurring.<sup>ii</sup>

Moreover, reasonable estimates of the average value of a system cannot be derived by using average values of the input parameters (such as demand for a product, its performance, etc.). Contrary to naïve assumptions, an analysis of the performance or value of a system using average estimates of uncertain parameters does not lead to a good estimate of average

performance of the system. In general, the actual average general differs substantially from the naïve estimate. This reality is embodied in Jensen's Law, stated formally as:

$$EV [ f(\mathbf{x}) ] \neq f ( EV\{\mathbf{x}\} ) \quad \text{where } \mathbf{x} \text{ is the vector of inputs.}$$

The reason for the non-equivalence is because of non-linearities in the valuation function  $f(\mathbf{x})$ . These occur for all kinds of reasons, an obvious one being those associated with capacity restraints. Where these exist, they may limit the upside potential of a system, so that the limited increases in benefit from higher demand cannot compensate for the unlimited decreases in benefit associated with lower demands. (de Neufville, Scholtes and Wang, (2006) illustrate this phenomenon in the context of infrastructure investments).

Traditional evaluation procedures are therefore not adequate, due to both the uncertainties associated with the deployment of major innovative systems and the complicated, non-linear relationships between costs and results. Because the traditional evaluations are based on a single sequence of possible outcomes (generally defined by averages or best estimates) they provide measures that will be inaccurate at best, and most likely to be misleading. Specifically, the usual versions of benefit-cost (BCA) and discounted cash flow (DCF) analyses that give single numbers are inappropriate for evaluating alternative designs or development plans for complex, innovative systems with great uncertainties.<sup>iii</sup>

Benefit-cost analyses can, however, be adapted to evaluate uncertain outcomes. Moreover, this can be done consistently with the US national guidelines (US OMB, 1992) that indeed recommend that uncertainty be explicitly taken into account. Rivey (2006) demonstrated how this could be done through an in-depth study of FAA investments. This paper further illustrates this point in the ITS environment.

### **Dealing with Uncertainty**

To deal properly with uncertainty, we need to adjust both our design concepts and evaluation procedures.

As regards the design, an uncertain environment motivates flexibility in deploying investments. Most importantly, the deployment process should be flexible about the way the system is developed, adapting the design as new opportunities and threats arise. It should also, of course, be flexible about the rate of implementation over time. System managers will want both to be positioned so as to be able to respond to new opportunities, and complementarily, to get out of unproductive situations. The history of the US Federal Aviation Administration (FAA) in

developing advanced landing systems for airports is instructive. In the 1970s work started on early versions of Microwave Landing Systems, which require extensive ground equipment. The Government committed to this system as the solution for the next generation and focused on its development. In the 1990s, however, their plans were overtaken by the Global Positioning System (GPS) technology based on satellites. The FAA then found itself in the awkward position of neither having the flexibility to shift easily to this alternative technology, nor being able to exit gracefully from previous but now obsolete commitments (see Wikipedia 2007b for a brief history). A flexible design and deployment strategy would have served them better.

As regards evaluation, it is necessary to adopt a procedure that can value the system with flexibility. The conceptual difficulty here is that, by definition, the system may evolve in different ways, each of which implies a different stream of annual benefits and costs. Thus, a flexible system does not have a single cash flow, as required to complete a traditional Discounted Cash Flow or Benefit-Cost Analysis.

This paper addresses both these issues. It shows how flexibility can be introduced into systems design (technically in the form of “real options”), and then combines decision analysis and real options concepts to use “*hybrid real options*” to value flexibility that can be achieved via various R&D and deployment strategies.

## **CONCEPTS OF OPTIONS**

Throughout this paper, the word “option” has the specific technical meaning that is much more restrictive than the way the word is used in ordinary language. That is:

An “option” endows its owner with the  
“right, but not the obligation”  
to carry out a specific action in the future.

The George Washington Bridge across the Hudson River in New York, and the 25 de Abril bridge across the Tagus in Lisbon, provide classic examples of options embedded in engineering design. Each structure was built with extra strength, which gave the owners of the bridges the “option”, that is the “right, but not the obligation”, to double deck their bridge (the specific action) if ever the conditions were appropriate (in the future). In neither case were the owners of these systems obliged to add to these structures, let alone at a particular time. They could do so when appropriate, if ever. They also could choose to build more highway lanes, or, alternatively rail lines if eventually suitable.

The definition of an option as a “right, but not an obligation” contrasts with the way everyday language uses the word as a synonym for “choice”. Generally speaking, a choice is something

you may decide to do, and then that is done. When you select an “option”, on the other hand, you give yourself the flexibility to do or not do something, or even a variety of things as in the case of the several ways to expand the capacity of the bridges.

### **Types of Options**

For clarity, it is useful to distinguish among 3 versions of options:

- Financial options,
- Real Options “on” projects,
- Real Options “in” engineering systems.

This paper focuses on the third version, the use of options to optimize the technical configuration of the deployment of a system.

Financial options are most common. These involve financial contracts between people or organizations in which one sells to another the ability to execute some future financial transaction. Most ordinarily, a financial option gives the holder the right to acquire some asset (company shares, barrels of oil, foreign exchange, etc) at a fixed price some limited time in the future (usually, until a specified date). Such options are routinely traded in open financial markets. Collectively, the markets for financial assets involve trillions of dollars annually. Most of the theory and literature on options concerns financial options.

Real Options, by contrast, deal with unique physical assets, such as factories or other means of production (for example, aircraft). (Myers, 1984) Most discussions of this class of options present extensions of financial assets to these physical assets, and treat the technology itself as a “black box”. In general, these options refer to the owners’ capability to open or close a facility, or to defer the construction or expansion of a project. Overall, these options that do not involve design issues can be referred to as “Real Options “on” Projects”.

The options of particular interest to system designers are those that involve specific features or configurations of design. These are called “Real Options “in” Systems”. (Wang, 2005; Wang and de Neufville, 2005, 2006). The bridges cited above had such options: their design involved extra steel and strength that enabled various forms of expansion, and this flexibility only existed because the designers had taken special steps to provide them. Of course, additional costs may be involved in providing this flexibility. Likewise, the development of ITS, where choices have to be made concerning the design of the systems, can also involve real options “in” systems.

## Reasons to Use Options

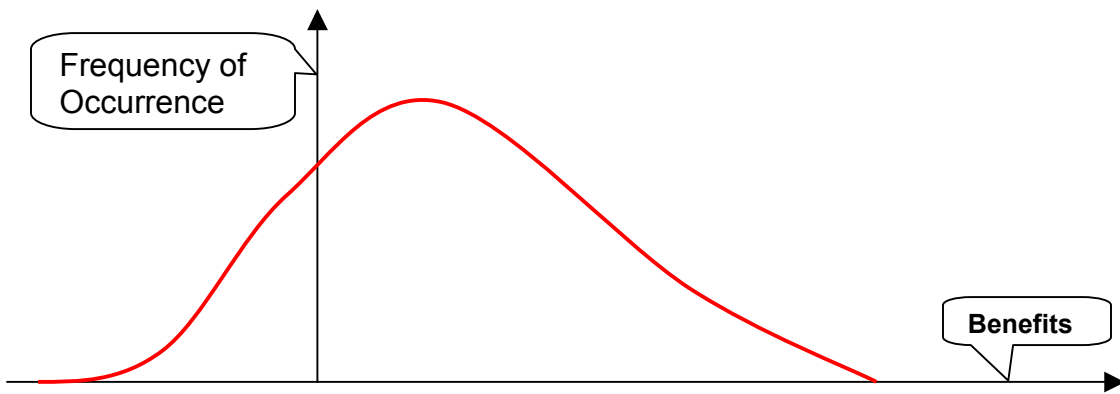
Options enable the system operators to reconfigure their system when appropriate to do so. They give system managers the flexibility to defer choices until later on, when they have seen how the future actually develops. The owners then can respond appropriately, either by avoiding an inappropriate decision, or taking advantage of new opportunities.

The case of the 25 de Abril bridge at Lisbon illustrates the point. When the Portuguese built the bridge in 1966, they could have chosen one of three basic configurations:

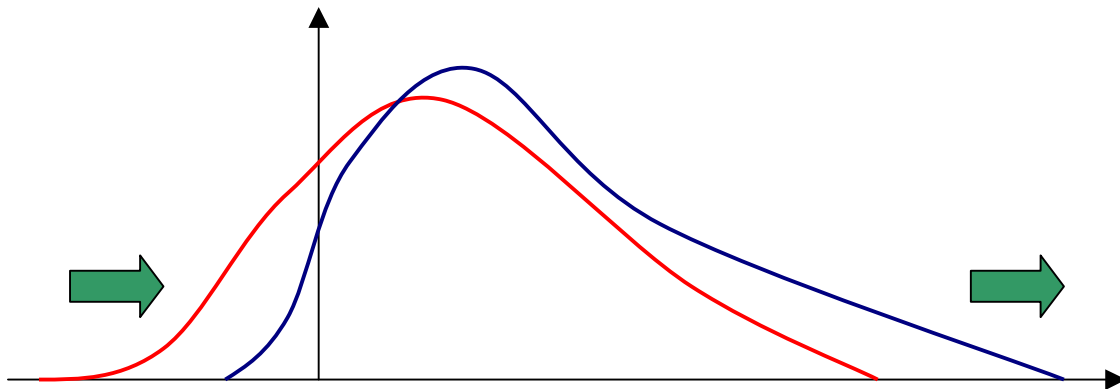
- Single-deck bridge;
- Double-deck for automobile traffic alone;
- Double-deck for cars and rail traffic.

Using standard design practice, they would have calculated the costs and benefits of these designs based on their forecast traffic, and chosen one configuration. Having done so, they would have run the great risks of not having enough capacity, or having no space for rail traffic, or having space for rail traffic, but no rail system to use it. By providing extra strength in the bridge so that it could later be developed to respond to future events, they eliminated these risks of having the wrong kind of facility. In retrospect, trend-breaking events occurred that completely changed previous forecasts. The overthrow of the dictatorship, the integration of Portugal with the European Union, and the availability of European Community grants to build a subway system opened up possibilities that could hardly have been predicted or even envisaged when the bridge was designed. Because the designers had built a real option “in” the bridge, its owners were uniquely able to take advantage of these new opportunities, although at some cost. (Gesner and Jardim (1998) provide a description of the double-decking process.)

More generally, options enable system managers to manage risks. The fact is that the future outcomes of a long-term system are not known in advance. As indicated by the fact that forecasts of the demand for a service are unreliable, the future benefits from a systems may be excellent, they may be terrible, and may be somewhere in between. In general, there is a small likelihood of extreme conditions, and greater chances of in-between results. To put this mathematically, there is a distribution of outcomes, as Figure 2 illustrates.



**Figure 2: Example Distribution of Outcomes of a System.**



**Figure 3: Effect of Real Options in Design is to shift distribution of outcomes by reducing downside and increasing upside potential.**

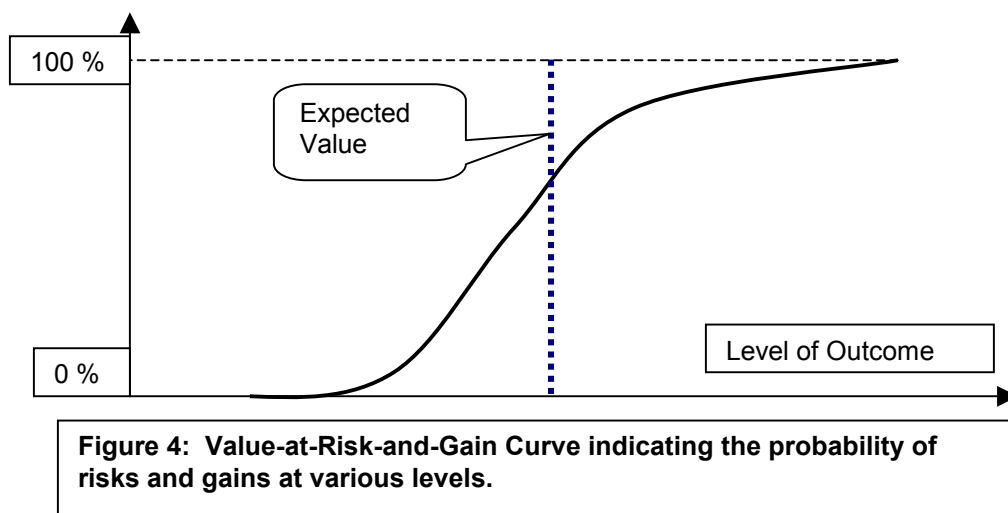
### **Value-at-Risk-and-Gain (VARG) Curve**

In graphical terms, the use of real options enables the system managers to shift the distribution of outcomes to the right, as Figure 3 indicates. Avoiding downside risks reduces the left-hand tail, and maximizing the upside opportunities increases the right-hand of the distribution. The net effect is to increase the expected value.

The value-at-risk-and-gain plot is a convenient way to present the range of results for any system design, and then to compare designs. It is the cumulative distribution of the potential results of a system, as Figure 4 shows. The notion of value-at-risk derives from the way financial analysts use the curve to estimate the downside potential loss from projects, at any specified level of risk.

Complementarily, the plot equally shows the value-at-gain, the upside potential that might be achieved. The VARG curve has the advantage of succinctly presenting several measures of performance for alternative system designs, any of which may be of significant interest. As Figure 4 indicates, the VARG shows the:

- Expected value – that designers want to maximize, if reasonable to do so;
- Maximum possible loss – that risk-averse designers and owners will want to minimize, even at the expense of loss overall expected value; and
- Maximum possible gain – that is desirable to maximize, and is often the prime criterion of venture capitalists and other risk-seeking investors



Reduction of the capital expenditures (CAPEX) needed to create the system is another important likely benefit of the use of real options. This advantage occurs because the converse of creating flexibility in design, of enabling the system managers to make the right investments later on, is to defer those investments. Thus, with the bridge over the Tagus: the expense of creating the second deck on the bridge was postponed by more than 25 years. Reduced CAPEX is an immense advantage, because the present value of capital expenses deferred by many years is very small. This benefit of the use of options is not apparent in the VARG presentation, however.

### Option Value created by Uncertainty

The value of an option increases with uncertainty. This is a remarkable phenomenon, often counter-intuitive. It deserves careful attention and understanding. Indeed, all else being equal, riskier assets are less valuable. In choosing between two investments each with the same expected returns, it is rational to choose the one with less risk. The value of an option differs from other classes of investments, however: the riskier the situation, the more the option is worth.

Options derive their value from uncertainty and risk. In the face of uncertainty, they enable the owners to choose the right investment later on. If there were no uncertainty, we would do the right thing now, and be done with it. Uncertainty creates the value of the option. The value of flexibility derives from our current uncertainty about what is the best thing to do. As with the Tagus bridge, the real option “in” the system enabled the Portuguese to avoid making a wrong choice (avoiding a loss is good) and of making the right choice when it became apparent what that would be (another good), while deferring the CAPEX investment (yet more good). In general, the greater the uncertainty in the underlying driver of value, the greater is the value of flexibility.

Because real options are most valuable when the future is uncertain, they are especially valuable for large-scale, innovative, long term developments. Such projects can indeed be very uncertain, and thus stand most to benefit from the appropriate use of real options. However, real options may involve some up-front costs. Therefore we need a way to value the flexibility we “buy” to compare it with these costs. The next section discusses this valuation process.

## **REAL OPTIONS VALUATION**

The process for valuing financial options developed rapidly after Merton (1973), and Black and Scholes (1973) did their fundamental work that won the Nobel Prize in economics. Powerful analytic processes followed from this work. However, these procedures make assumptions and require data that are either untenable or unavailable to designers of engineering systems, as indicated below. In the design of engineering systems, alternative procedures as presented in this paper are thus necessary to be able to value, and thus justify the use of real options and flexibility.

### **Economic Theory**

From a theoretical perspective, the proper valuation of an option is complicated from two points of view. An over-arching reason is that the uncertainty associated with any system varies over time, as various uncertainties are resolved and new factors emerge. This fact implies that the valuation of options should use different discount rates over time, properly adjusted for the level of varying risk. Standard discounted cash flow or engineering economy approaches cannot deal with this requirement satisfactorily – they are based on using constant discount rates.

A further difficulty in evaluating options is associated with the drivers of value for market-traded assets (such as company shares, oil, foreign exchange, etc). This arises because traders of such options can set up “replicating portfolios”, that is, combinations of assets and loans, which will exactly match the outcomes that the options enable. Since the replicating portfolios have the

same outcomes as the options, they must have the same price. Thus, the value of the option can be determined by the value of the replicating portfolio. Because traders can exactly balance this with an option, it can be evaluated at a constant risk-free discount rate. This process, known as “arbitrage enforced pricing”, determines the value of the option.

Further, the usual economic analysis of options rests on many assumptions. It requires good estimates of the uncertainty. For assets traded in markets, these can be obtained by observing the extensive record of daily trades over long periods. The analysis also assumes that future uncertainty derives from random variations around current conditions (that it is essentially white noise), and is unaffected by conditions prior to current observations (the path independency condition). These conditions are justified on the basis that the trading markets are “perfect” in that they embody all available information and that no one has any special inside information.

Such assumptions are the basis for the widely used Black-Scholes formula. This actually only applies correctly only to certain cases. Subsequently, many economists have developed a range of means for calculating the value of options for assets traded in markets. The most widely used approach is the lattice method developed by Cox, Ross and Rubinstein (1979).

### **Deficiencies of Economic Approach for Design**

The economic form of options analysis is powerful and effective for short-term markets. It has revolutionized international finance and trading of commodities. However, it does not work well when a trend-breaker occurs – as the multi-billion dollar catastrophic 1998 collapse of Long Term Capital Management demonstrated [Wikipedia, 2007a]. Nor is it correct when the assumptions on which it is based do not apply – which is often the case for the engineering systems.

The standard financial procedures for valuing options cannot be assumed to apply to Real Options “in” Systems. In particular:

- It is implausible to estimate precisely the standard deviation of the uncertainty for innovative systems, such as ITS, for which there is no experience. Furthermore, only some of them are observable and other depend upon the use of the option.
- In any case, markets often do not exist for the services provided by engineering systems, so that there is typically no data on their fluctuating value.
- When, as is usual, there is no market for these services, there is no possibility of creating “replicating portfolios,” and the justification for “arbitrage enforced pricing” evaporates.
- Equally, the assumption that future conditions are some kind of white noise extrapolation from current conditions, based on a perfect information market, also vanishes.

- Future conditions for an infrastructure system generally depend on previous conditions – precisely because system managers react to ongoing developments, and change the design and performance of the system, as Wang et al (2006) demonstrated.

Financial procedures can plausibly be used to evaluate Real Options on some engineering systems. Generally speaking, they apply to projects that produce some commodity – such as copper or electricity -- that is routinely traded in markets. Examples of this occur in mining (Brennan and Schwartz, 1985; Tufano and Moel, 1999) and power production (Kulatilaka, 1993). This class of projects does not include transportation systems that deliver connections, speed, safety and other non-market consequences.

### **Practical Approaches for System Design**

Practical approaches to the valuation of flexibility in system design generally use one of three approaches:

- Decision analysis
- Simulation,
- A Hybrid combination of the above.

The choice between them depends upon the situation, as Chambers (2007) indicates.

A decision analytic approach provides a convenient way to present and analyze cases in which there are several discrete uncertainties – for example when there is probability of a “go/no go” decision or event, such as the approval of a program or the passage of legislation. This approach is defective from a theoretical perspective because it does not easily permit the appropriate use of varying discount rates as the uncertainties evolve. However, it has the great merit of enabling the exploration of the realistic cases that traditional economic analyses cannot handle practically. Indeed, system designers have to deal with many uncertainties (for example, concerning R&D success; governmental regulation; market penetration, etc.) – and conventional options analysis deals with only one kind of uncertainty. Further, the uncertainties facing designers are often discrete (for example, a new law will or will not be passed; a competitor will or will not enter the market) and conventional analyses can only handle these “jumps” with difficulty. As Ramirez (2002) and de Weck et al (2005) demonstrated, decision analysis thus permits a feasible approach to the analysis of flexibility in many important cases beyond the reach of financial economic options analysis.

Simulation offers an effective way to handle uncertainties with complex distributions around a variety of forecast trends. It is particularly convenient because it is available as an add-in for spreadsheet programs and thus quickly values flexibility from basic data on benefits and costs.<sup>iv</sup>

This approach has been successfully used to evaluate flexibility in a wide variety of contexts (Greden et al, 2005; Hassan et al., 2005; de Neufville et al. 2006).

The hybrid approach combines both these approaches. As originally described by de Neufville and Neely (2001), it combines decision analysis for those parts (such as the R&D process) that feature multiple discrete uncertainties, and some form of simulation for aspects (such as market penetration of a product) that diffuse continuously over time. The hybrid approach appears most practical for complex systems that incorporate a wide range of uncertainties that cannot conveniently be handled by a single approach. It is the approach applied to the case study of the ITS system. It is presented in detail in that context.

### **CASE STUDY: DESCRIPTION OF ITS APPLICATION**

To illustrate how a flexible approach to system design and deployment can increase its expected value, we examined an application in ITS. This technology is a good example of the kind of complex, large, innovative systems that are the focus of much of public and private interest. It:

- offers great potential for exploiting information technology beneficially;
- requires coherent large-scale planning;
- entails the alignment of a broad range of stakeholders;
- involves great technological, social and industrial uncertainty; and
- Is under continuing research, which may substantially affect its costs and benefits.

### **Background**

Intelligent Transportation Systems use information technology to improve the flow, safety and monitoring of vehicular traffic. In general, ITS involve both in-vehicle and infrastructure elements. Electronic toll collections systems illustrate how this works: strategically placed sensors pick up signals from transponders in passing cars. This description highlights a core issue faced by managers of ITS. To be effective, ITS require coordination between the infrastructure and private users who pay for the in-vehicle devices.

As Sussman (2005) described in detail, ITS have great potential. Beyond automating and increasing the efficiency of standard practices, such as toll collection, ITS could provide important new societal benefits such as reducing congestion through variable pricing of travel at particular times or areas. In particular, ITS could significantly increase safety by warning drivers about impending collisions, much as the TCAS (Traffic Collision Avoidance System) now alerts pilots about potential in-flight collisions.

The implementation of ITS poses great challenges and risks. ITS is usually viewed as a partnership between the public sector, which typically provides roadside infrastructure of various types, and the private sector that provides in-vehicle technologies. For effective ITS operations, the roadside infrastructure and in-vehicle technologies must be linked, which may require considerable cooperation between the public and private sectors. Yet the goals of the public and private sectors differ. The public sector is interested in creating benefits for the public at large, and the private sector, while subscribing to public benefits in general terms, is concerned with ITS either as a for-profit enterprise or for benefits accruing to individual purchasers of the in-vehicle equipment. Moreover, insofar as private users do not choose, or are not required to invest in the in-vehicle devices, the ITS will not be fully effective. The resolution of this tension between the public and private sectors is difficult to define in advance.

### **Intersection Collision Avoidance Systems (ICAS)**

The prevention of intersection collisions is a prime prospective area for the use of ITS. Highway accidents entail huge material and social costs. According to the US National Highway Traffic Safety Administration (NHTSA), automobile vehicles crashes in the United States in the year 2000 cost a total of \$230 billion. This represents the present value of lifetime costs for 41,821 fatalities, 5.3 million non-fatal injuries, and over 27.5 million damaged vehicles (Blincoe et al, 2002)<sup>v</sup>. Even small improvements would have great value.

“Intersection Collision Avoidance Systems” (ICAS) is the collective name for ITS designed to achieve this purpose. As detailed by the US Department of Transportation (US DOT 2005), ICAS come in three major competing versions:

- Infrastructure autonomous: roadside units that communicate with drivers -- visually (flashing signs or other) or electronically to vehicles;
- Vehicle-based: On-Board Units (OBU) that read from and write to intersection warning devices; and
- Hybrid units that combine elements of both systems.

The investments required for and the associated performance of each system differ greatly.

The infrastructure autonomous ICAS require large initial investments in infrastructure, generally by the public<sup>vi</sup>. It is not an approach that can be deployed in small increments, as consumer goods can be. It has an important compensating advantage however; its effectiveness does not depend on the market penetration of the OBU. Thus, all vehicles will benefit immediately from using intersections equipped with infrastructure autonomous ICAS.

Vehicle-based ICAS have contrasting characteristics. They do not require great investments in infrastructure. The cost of the system can be carried by private users that would pay for OBU incrementally, much as they pay for on-board GPS or satellite radio. However, in further contrast with the infrastructure autonomous ICAS, this system only benefits vehicles equipped with OBU (and secondarily, those into which they might – but don't-- crash). Thus the effectiveness of vehicle-based ICAS depends directly on the degree of market penetration of the OBU.

Hybrid systems mix some of the above systems. For example, the infrastructure autonomous system might send out electronic warnings to on-board processors that could initiate warnings to drivers or countermeasures such as applying brakes. Likewise, sensors around intersections could enhance the performance of in-vehicle systems. Any ICAS that might be deployed almost inevitably will have at least a flavor of both systems. Naturally, hybrid systems will have some characteristics of the basic systems.

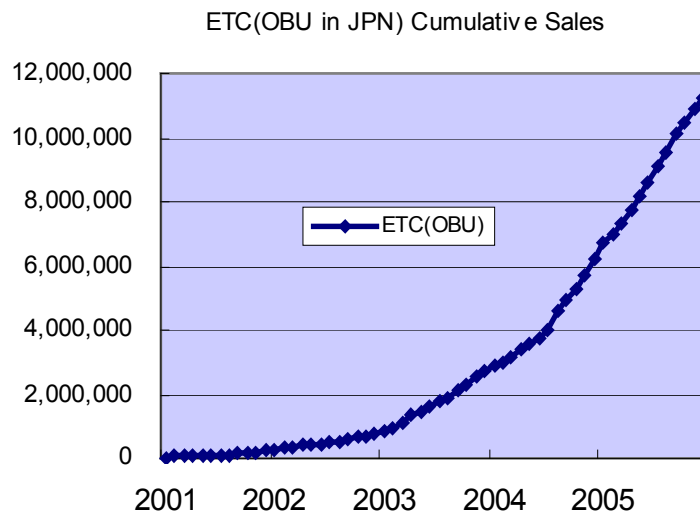
#### **Diffusion of On-Board Units (OBU)**

The potential rate of adoption of the in-vehicle devices is a major uncertainty associated with the development of intersection collision avoidance systems. It strongly affects the rate of delivery of benefits, in terms of accidents reduced, and thus the value of the system, particularly of those that depend most on the use of OBU. The rate of adoption thus may eventually turn out to be a decisive factor in a future selection of which kind of system to implement.

The rate of diffusion of any innovation into the vehicular fleet is inevitably slow. This is because quality improvements over the past 50 years have greatly increased the life of automobiles. The expected life of a car in the United States has been on the order of 13 years. This means that if some feature (remote control key locks for example) is installed on new cars, it takes a long time for this innovation to pervade the fleet. Even if the device is mandated for all new vehicles, it would take about 13 years until "all" cars would be equipped with it (some cars would last longer than the average, and some would indeed be prized for their vintage). The rate of diffusion can be accelerated to a limited extent when the innovation can be retrofitted on existing vehicles, much as transponders can be attached to cars for electronic toll collections. However, even under the most optimistic assumptions it would take more than a decade for any OBU technology to diffuse throughout the vehicle fleet. More realistically, recognizing that governments usually introduce mandates gradually, this process may take a generation (de Neufville et al, 1996)

The historical diffusion of OBU for electronic toll collection (ETC) provides an indication of how fast such devices might penetrate the market. Consider the national record for Japan, which has been a leader in this regard. As Figure 5 shows, Japanese drivers bought (and presumably

installed) over 11 million such units in 5 years. This is impressive. However, these sales translate into only about a 20% penetration of their national vehicular fleet, which was about 60 million in 2006 (Encyclopedia Britannica, 2007). Considering that ETC transponders are relatively inexpensive compared to the cost of a vehicle (in Massachusetts they sell for about \$20), their adoption is fairly painless and the benefits—avoiding the wait to pay tolls—is clear. Yet the adoption of these OBU is fairly slow: some drivers may not use the highways equipped with the infrastructure that would use these units, others simply cannot be bothered to acquire and install this retrofit. In short, the diffusion of OBU is likely to be a slow, uncertain process.



**Figure 5: Cumulative Sales of the OBU for Electronic Toll Collection in Japan (Source: Japan 2006a)**

### Technical Uncertainties

The performance of any eventual ICAS must be speculative. At the most basic level, these systems are currently research projects. Their effectiveness in preventing accidents is not yet determined. Moreover, there are many different types of intersection accidents (Peirowicz et al, 2000), and alternative detection and warning systems will inevitably work better in some conditions than in others. Further, the aggregate success of any system depends on its distribution, given that the frequency of accidents at intersections varies widely, as Japanese researchers have demonstrated in detail (Japan, 2004, 2006b).

To illustrate the proposed procedure for using options analysis, the analysis used estimates of the short term probability of success of an ICAS. Without making any claims of prognostication, the analysis assumed that the ICAS could have Medium Success, with probability of 60%. It might in fact have High Success (probability = 30%), or be a complete failure (probability = 10%).

Alternative assumptions would not alter the demonstration of the procedure, or the conclusions about how flexibility in system design can improve the expected performance of a system.

The analysis also assumed that the rate of market penetration of the on-board units would depend upon the relative technical success of the ICAS system. Naturally, people are more likely to adopt the technology if it performs well. Specifically, the analysis assumed that the adoption rate would have an 80% chance of being fast, and a complementary 20% of being slow if the R&D were highly successful. If the R&D had medium success, it was assumed that these probabilities were reversed. As with the previous assumptions, these are satisfactory for the purpose of demonstrating the procedure.

### **CASE STUDY: BASE CASE ANALYSIS**

The base case is a standard benefit-cost analysis. It provides the norm compared to which it is possible to appreciate the benefits of the options analysis. The base case calculates the value of the decision to commit to the development of the ICAS. This may be compared to the Null Alternative of not pursuing this technology. For illustration purposes, the analysis concentrated on the value of the OBU technology, which requires the least public expenditure and seems to maximize the private participation in the deployment of the ICAS technology (through the purchase and installation of the OBU).

The standard approach focuses on the most likely outcome. In this case this would be (given the assumptions described above) that the R&D process would have medium success, after which there is a stream of benefits with a Net Present Value of \$2.3 billion (as in Table 1 indicates). Noting carefully that this result depends on debatable assumptions, we are not claiming that this is a solid estimate of the benefits of the OBU-based ICAS technology, nor are we presenting this analysis as a good basis for investment decisions. Having made this disclaimer, we note that this estimate is not unreasonable, given that the annual cost of intersection collisions is on the order \$230 billion (as indicated above) so that even a minimally successful ICAS system could be worthwhile.

It should be emphasized that standard estimates of value focus on a single, most likely flow of benefits. They do not indicate the risks that might be incurred. Thus the \$2.3 billion estimate of value for an OBU-based ICAS system does not indicate any risks. Yet the investment is most likely to have only moderate success, which is why the estimated value is so low compared to the size of the problem. We discuss the issue of risk below, in the context of the VARG analysis.

## **CASE STUDY: THE OPTION ANALYSIS**

The investment in the R&D for the development of the ICAS creates the option to invest further in the system. If the R&D is successful, the “right, but not the obligation” to implement the system exists. At that point, the system managers can decide if it is worthwhile to invest in the implementation phase. In many cases, it will not be advisable to invest in a full system, even if the R&D has been successful: the implementation costs may appear too high compared to the benefits – for example if a competitive technology offers better value.

Thinking of investing in the R&D process to create an option – and leaving the subsequent development open – is fundamentally different from committing to the system from the start. Buying only the R&D is relatively inexpensive, compared to the deployment of the system. Also, it provides the flexibility to walk away from the system if it appears not to be sufficiently worthwhile. This may occur either because system is not sufficiently valuable given the then current market conditions, or because the research is not paying off sufficiently rapidly. A commitment to the system from the start does not permit abandoning the project – much as the FAA had difficulty walking away from the Microwave Landing System (MLS) when GPS promised superior performance.

The recommended procedure for analyzing the value of flexibility of technological systems merges two approaches. This hybrid approach combines a lattice analysis (Cox et al, 1979) with a decision analysis. As de Neufville and Neely (2001) describe, it applies each to the uncertainty for which it is most suited.

A “random walk”, or lattice analysis conveniently projects possible future states that may occur for a process that varies around a steady long-term trend. Such processes are characteristic of the evolution of prices for stocks and other widely traded assets. Thus lattice analysis (or some variant) is the fundamental approach used in the financial analysis of options.<sup>vii</sup> These processes do apply to a limited extent for the analysis of complex systems. For example, it is arguable (although debatable) that the growth in demand for services may often reasonably be represented by a lattice.

However, many uncertainties associated with complex technical systems cannot be properly represented as steady evolutions following a smooth distribution. In general, the development of an engineering system has to deal with a collection of discrete choices. For example:

- Will the research be successful?
- Will the government decide to fund a program?
- Will new environmental or other regulations be imposed?

A lattice analysis does not appropriately model these kind of discrete, yes/no, “go/no go”, “jump” uncertainties.

Rather, decision analysis is the appropriate way to investigate the implications of discrete uncertainties. This approach is inherently discrete. It can thus easily analyze the jump uncertainties that characterize many technological systems. For example, Chambers (2007) used decision analysis to investigate the flexibility of airport development in the context of uncertainties about the airline future (will the national carrier survive or not?). In the case of the ICAS, decision analysis is the appropriate way to consider uncertainties associated with the success of research in this area.

### **Lattice Analysis**

The essence of the lattice analysis is to project forward the broadening range of possible outcomes that could develop from a starting point. This is almost universally done using a binomial process that projects how a process might evolve. Thus from the starting point (say a given level of traffic), traffic might increase or decrease; from either of those 2 possible outcomes, traffic could further increase or decrease. The lattice process is carefully calibrated to maintain the characteristics of the steady process being modeled, that is to replicate the desired trend and standard deviation of this process. Luenberger (1998) provides a good textbook description of this process.

Figure 6 shows a lattice projection for a particular set of assumptions – in this case that the research is successful and that the evolutionary trend of the deployment is fast. Other lattices are appropriate for different trends that might be assumed, for example that the deployment were slow on average. As conventional, the lattice shows time increasing toward the right. The lattice indicates that the annual benefits would be negative and small at the start, and generally increase over time. It also shows that the range of possible states expands over time: the further one projects ahead, the wider the uncertainty. According to the binomial logic associated with the approach, each cell has a probability associated with it: thus the probability of the two states in the first year might be 50:50; that of the 3 states in the second year might be 25:50:25; and so on.<sup>viii</sup> This lattice shows that the eventual benefits become very large (about \$2 billion/year), in keeping with the assumption of an ICAS that successfully reduces the losses from vehicle crashes. It may be noted that the uncertainty in this lattice is tight (about 2400 +/- 10% after 20 years) and it would be reasonable to suppose greater uncertainty. However, the actual numbers used in the example analysis are not crucial for the purposes of illustrating the procedure.

Lattice analyses similar to that shown in Figure 6 were done for each of the associated discrete uncertainties considered in the decision analysis. For each year, the expected value was calculated; these sums were discounted to the present and summed; and the estimated net present value associated with each scenario was obtained. Table 1 summarizes these results.

Revenue Lattice																				
	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
0	-19	-18	-17	-52	-51	-35	9	99	247	449	692	959	1237	1513	1782	2036	2274	2493	2614	2618
1		-18	-17	-52	-51	-35	9	98	244	444	685	950	1225	1499	1764	2017	2252	2469	2589	2593
2			-17	-51	-50	-35	9	97	242	440	678	941	1213	1484	1747	1997	2230	2445	2564	2568
3				-51	-50	-34	9	97	240	436	672	932	1201	1470	1730	1978	2209	2421	2539	2543
4					-49	-34	9	96	237	432	665	923	1189	1456	1714	1959	2187	2398	2514	2518
5						-34	9	95	235	427	659	914	1178	1441	1697	1940	2166	2375	2490	2494
6							9	94	233	423	652	905	1167	1428	1681	1921	2145	2352	2466	2470
7								93	230	419	646	896	1155	1414	1664	1902	2124	2329	2442	2446
8									228	415	640	887	1144	1400	1648	1884	2104	2306	2418	2422
9										411	634	879	1133	1386	1632	1866	2083	2284	2395	2398
10											628	870	1122	1373	1616	1847	2063	2262	2372	2375
11												862	1111	1360	1601	1830	2043	2240	2349	2352
12													1100	1346	1585	1812	2023	2218	2326	2329
13														1333	1570	1794	2004	2197	2303	2307
14															1555	1777	1984	2175	2281	2284
15																1760	1965	2154	2259	2262
16																	1946	2133	2237	2240
17																		2113	2215	2219
18																			2194	2197
19																				2176

**Figure 6: Lattice projecting value of benefits of ICAS with On-Board units over 20 years, if the research were successful and if the OBUs penetrated the market fast. (\$, millions)**

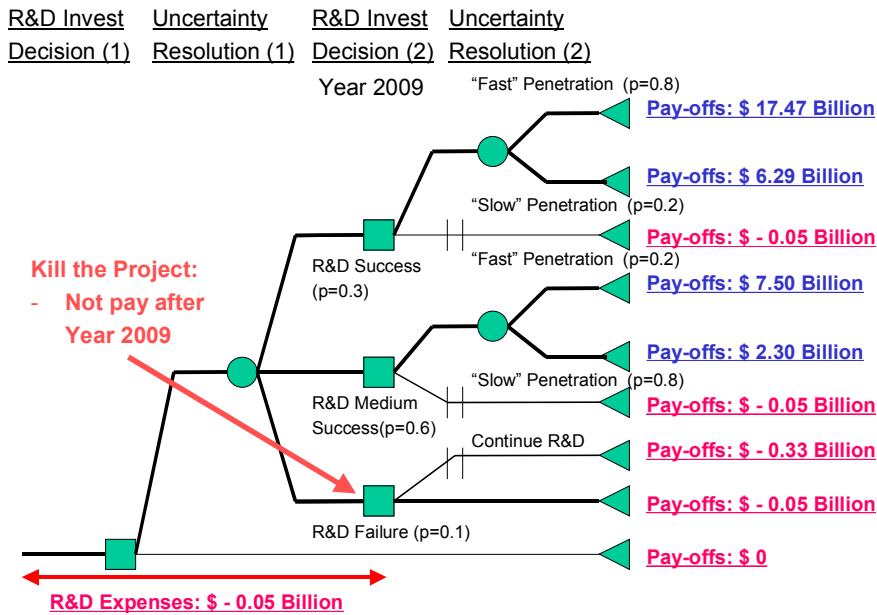
**Table 1: Summary of Net Present Values associated with each scenario for the ICAS with the On-Board Units**

R & D Outcome	OBU Market Penetration	Net Present Value (\$, Billions)
Good	Fast	17.4
“ “	Slow	6.29
Medium	Fast	7.50
“ “	Slow	2.30

### Decision Analysis

The complete hybrid analysis uses the lattice analysis as input to the decision analysis. In this case, it provides the values of the possible outcomes that could occur in each of the 4 scenarios resulting from discrete uncertainties regarding the success of the research and the speed of market penetration of the on-board units. Figure 7 illustrates this process. It shows the possible consequences of deciding to proceed with R&D for the ICAS, of observing the results after a first phase; of maintaining the flexibility to cancel the system if results are unsatisfactory, but committing to development with uncertain outcomes at the end of the second phase.

Decision Analysis: Concept 3 (Vehicle-Based System)



**Figure 7: Decision Tree for ICAS with On-Board Units, combining results of Lattice Analysis.**

The value of the investment in the OBU-based ICAS is now calculated to be \$6.7 billion in expected net present value:

$$\text{Expected Value of Decision} = 6.7 =$$

$$\sum (\text{probability of research outcomes}) \sum (\text{probability of penetration}) (\text{outcome})$$

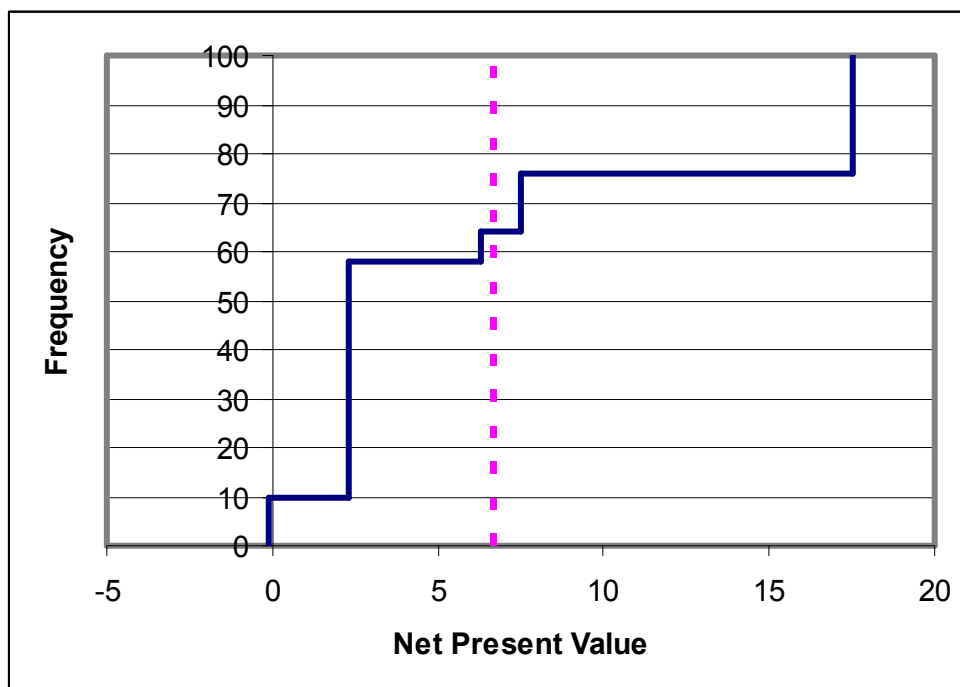
In this instance the great increase is due to two factors:

- Great upside potential if the R&D is highly successful, even if this is not highly probable; and
- Limited downside, represented by the write-off of the investment in the R&D process.

Note that the result of the analysis is a strategy, rather than a fixed plan. In this case, it is that:

- It is worthwhile to invest in the R&D for the ICAS, because the potential value of the system is very large;<sup>ix</sup>
- However, it is important to recognize that the project is risky, and so to be flexible about continuing the process if the R&D process is not promising.

Thus, the strategy involves an eventual choice – if the ICAS opportunity appears promising after the research, take advantage of it; if however it does not, cancel the project and avoid the big losses that would result from a predetermined commitment to continue with the project.



**Figure 8: Value-at-Risk-and-Gain for the Investment in the Research and Development of the OBU-based ICAS.**

### **Value-at-Risk-and-Gain**

Figure 8 shows the Value-at-Risk-and-Gain for the commitment to the R&D process that creates the option. In this case, there is the possibility of reasonable value in general, with some possibility of very great gains. The possibility of loss is confined to the write-off of the R&D process if this turns out to be unsuccessful in developing a viable ICAS.

### **Value of the Option**

The value of the option, that is of only committing to investing in the R&D and leaving open the possibility of walking away from the project, is the value-added compared to the base case that commits to the ICAS from the start.

In this case, the savings represented by the possibility of walking away from the ICAS venture consist of the expenses that would be avoided by shutting down the R&D efforts. The amount saved would depend on what commitments had been made to a continuing effort. In this analysis we assumed continuing R&D costs of \$20 million a year, so that the net present value of the option to stop ICAS development if the research is unpromising is between \$150 and 200 million.

## **POLICY IMPLICATIONS**

The analysis has some interesting policy implications. While the numbers used are debatable, they do high-light some features of the situation that are worth considering:

- Size of the Prize: The potential savings that might be achieved through an effective Intersection Collision Avoidance System (ICAS) are so large (current annual losses estimated at \$230 billion of net present value) that some serious R&D efforts should be made. It would seem irresponsible not to investigate this opportunity, even though its outcome is highly uncertain.
- Modest Success may be sufficient: Even if only modest success can be achieved, it may be worthwhile to make some investment in the system. Again, this is because of the huge current losses due to crashes we now sustain.
- Success is not assured: It is entirely possible that it may not be possible to develop workable, reliable ICAS systems. The possibility of failure is real.
- Thus, a commitment to deployment is premature: Given the possibility of failure for the R&D efforts, it would be foolish to commit to the roll-out of any ICAS system until more is known.

The bottom line is that it would be good policy to invest in ICAS R&D as an option. This implies it would be appropriate to review the results after a reasonable period, with a view to cancelling the project if good results are not available. Put another way, an aggressive R&D program limited by a “sunset” provision would seem to be reasonable.--

## **CONCLUSIONS**

Real options add value to a system design. In general, they position the system to

- Take advantage of opportunities – in this case to develop the system if the R&D effort is successful; and
- Avoid bad situations – in this case to cut the losses if the experimental program does not work out.

In the case of ITS in particular, the options especially add value because this venture is still, at this stage, highly speculative, and this is where options are most valuable.

The worked-out example indicates how it is practical to conduct an effective options analysis in a technical system for which the traditional, financial approaches offer no effective approach. In particular, the hybrid approach makes it easy to deal with the different kinds of risks with methods appropriate to each. The decision analysis part is well adapted to yes/no discrete uncertainties, while the lattice analysis provides a good basis for considering gradually evolving situations.

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## Endnotes

<sup>i</sup> This is in a depressed area called the Lower Lee Valley.

<sup>ii</sup> This may seem counterintuitive and wrong. After all, a cursory look at a distribution (bell-shaped, say) might indicate that the peak of the distribution has a frequency of 20% at the value of X (say \$10 million) – therefore that one can conclude that there is a 20% chance of the value being \$10 million. More precisely, however, the distribution indicates that there is a 20% chance that the value lies within some range, say \$10 million +/- 0.5 million. Correspondingly, there is a smaller chance that the true value lies in a tighter range, say only 3% that it lies in the range of \$10 million +/- 0.1 million. Extending the argument, the chance that the value is exactly \$10 million +/- 0 is vanishingly small.

<sup>iii</sup> Note carefully that the inadequacy of the traditional techniques is in the context of projects with substantial uncertainties. When uncertainties are small, the traditional techniques serve an important role in ensuring economic rationality and consistency in corporate and governmental evaluation of projects. Indeed, the incorporation of discounted cash flow and the associated benefit-cost analyses into practice has been an important achievement since around the 1950s in corporate America, and the 1990's in the US Federal practice. For the latter, see US, OMB (1992).

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<sup>iv</sup> Many commercial products are available, such as Crystal Ball and @Risk. Basic simulation can also be trivially be added to Excel as shown in

[http://ardent.mit.edu/real\\_options/ROcse\\_Excel\\_latest/Excel\\_Class.html](http://ardent.mit.edu/real_options/ROcse_Excel_latest/Excel_Class.html)

<sup>v</sup> This figure includes the “property damage only” vehicles in which nobody was injured, which are not reported in the NHTSA’(2005) “Traffic Safety Facts”

<sup>vi</sup> It is conceivable that governments might arrange to have private concessionaires provide the service. However, the transfer of the investment risk to the private sector would be likely to involve a substantial risk premium, for which the public sector would end up paying.

<sup>vii</sup> This is also called a “random walk” process, particularly in financial discussions.

<sup>viii</sup> The example in the text is based a binomial that has an even chance of increasing or not. Alternative assumptions are possible and can be used to portray different, asymmetric distributions.

<sup>ix</sup> As the paper focuses on the process, the numerical results from the analysis are not presented, as we do not make a claim here as to the exact value of an ICAS system.