Real Options to Increase the Value of Intelligent Transportation Systems

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A practical approach was developed to calculate 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, a case study was followed for the deployment of a particular aspect of intelligent transportation systems: innovative crash avoidance systems that reduce accidents at highway intersections.

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. Indeed, our communities are now taking on mega projects, such as networks of high-speed rail service on a continental scale, as in Europe, and massive regional projects, such as the British redevelopment of 2 mi^2 of London for the 2012 Olympics and beyond.

Specifically, there is widespread 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.

Unfortunately, collectively, major projects have not yielded good value. As Miller and Lessard (*1*) 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. The desire to do better motivates the concern for efficient procedures for the deployment of engineering systems.

Great uncertainty is a signature characteristic of major infrastructure systems and is a root cause for unsatisfactory generation of value. Over the decade or more that it takes to design and develop the first stage of a system, there can be major changes in technology, the economic situation, governmental regulations, the industrial organization, and the political structure. Trend-breaking events regularly disrupt long-term forecasts.

A paradigm is needed for planning and designing large-scale engineering systems that deals effectively with the reality that the forecast is always wrong, or that it so regularly differs substantially from the actual future. Concepts and procedures to anticipate possible uncertainties, and deal with them efficiently as they arise are needed.

In a word, flexibility must be developed to react to events, take advantage of new opportunities, and exit from unproductive pathways. The expected value from a flexible system can be vastly greater than that of 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, procedures are needed to determine the value of development plans in the context of uncertainty—about both the future environment for the system and the response to these possible scenarios. Conventional methods of valuation—that is the discounted cash flow based on a point forecast of a single cash flow—are unrealistic when the future is uncertain. The real options paradigm provides a promising approach. It specifically provides means to value flexibility to deal with uncertainty. It thus provides a way to increase expected value from investments in the deployment of complex, large-scale, long-term infrastructure.

This paper presents an analysis of real options 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, flexible designs will provide more value. They systematically avoid bad outcomes and exploit good opportunities. To demonstrate the approach, the paper applies real options analysis to an anticipated deployment of ITS for avoiding collisions at intersections. As expected, the case study 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

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a percentage point or so, because circumstances do not generally change rapidly and because overforecasts in one sector cancel out underforecasts elsewhere. Over the decade or more associated with a major project, however, annual errors easily accumulate. As Figure 1 shows, 10- to 20-year forecasts for specific transportation systems have routinely proven to be off by 50% or more. Most important, the forecasts are not simply biased in a way for which decision makers can easily adjust. Empirically, the actual results are widely distributed around the original forecasts.

Trend breakers are important causes of major discrepancies between forecast and actual outcomes. These are major events that disrupt the patterns that formed the basis for the forecasts. They occur along several dimensions:

- 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 their manufacturers by surprise and bankrupting them.
- Economic and financial. Economic booms and busts can create new trends, as with the dot.com industry in the 1990s, or wipe them out, as deflation of land values in the 1990s in Japan undid the rationale for many urban developments.
- Regulations. Regulations can reshape industries, just as environmental regulations largely stopped the development of nuclear power plants in North America.
- Industrial. Changes in business models can revamp the relative strength of participants, as when the emergence of low-cost airlines precipitated the bankruptcy of most traditional airlines in the North America.
- Political. Changes in leadership and structure can redirect priorities, as when new U.S. presidents reorient the long-term objectives of the National Aeronautical and Space Administration, 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 such as ITS are inherently speculative.

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 alternatives. One focuses on deploying sensors and signaling systems in vehicles, the other places them mostly in the infrastructure at the intersections.

A primary uncertainty for the deployment of ITS technologies for intersection safety concerns the rate of market penetration of in-vehicle hardware. If all vehicles had appropriate hardware, the infrastructure component could be relatively minimalist, and most of the safety benefits would be achieved. However, if market penetration for in-vehicle hardware was low, the public sector would have to deploy more hardware at intersections to achieve safety benefits. This additional expense would be "wasted" to the extent it became obsolete when a large fraction of the vehicles are eventually appropriately equipped. 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, the cost of ITS intersection safety depends significantly on the unknown rate of adoption of in-vehicle safety equipment.

Uncertainties associated with market penetration are hard to estimate. They depend on many factors. For example, large public sector investments in roadside equipment might suppress the 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, 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. The estimates of the number of intersections that the public section might be able to equip with collision avoidance hardware must be speculative.

The second major uncertainty concerns the success of research and development efforts in creating suitable intersection safety hardware. Exactly when this hardware might be available in the marketplace and how much it might cost are far from certain.

The adoption of ITS for intersection safety is thus fraught with great uncertainties that depend on complicated interactions between

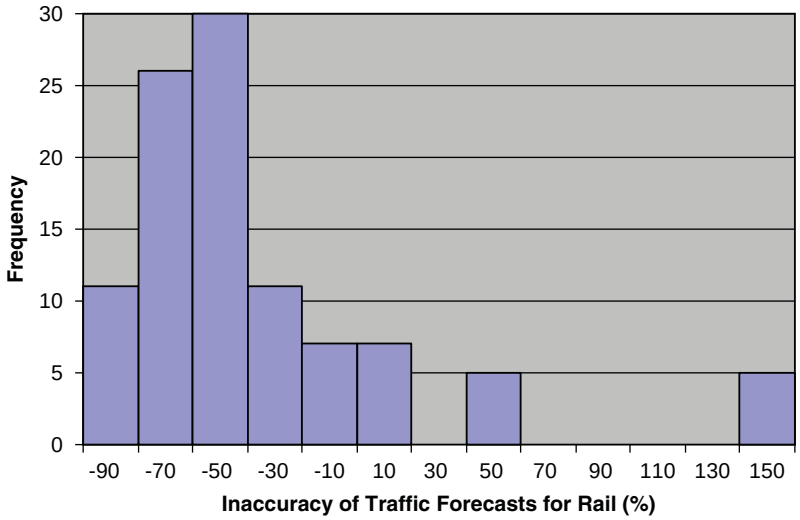

FIGURE 1 Data showing how forecasts for major projects are both "always wrong" and widely distributed from original expectations. [Adapted from Flyvjberg et al. (*2*, *3*).]

the public and private sectors. The public sector wants to be economical in its spending on roadside infrastructure and yet obtain safety benefits quickly. The private sector would like people to buy their equipment. The interests of the two will not always align.

Dealing with Uncertainty

To properly address uncertainty, both design concepts and evaluation procedures need to be adjusted.

With regard to the design, an uncertain environment motivates flexibility in deploying investments. 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 be flexible about the rate of implementation over time. System managers will want to be positioned so as to be able to respond to new opportunities and to be complementary to get out of unproductive situations.

With regard to evaluation, procedures are needed that can value the system with flexibility. The conceptual difficulty here is that 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 by 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 research and development and deployment strategies.

CONCEPTS OF OPTIONS

Throughout this paper, the word "option" has a specific technical meaning that is much more restrictive than the way the word is used in ordinary language. In this paper, an "option" gives 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 provides a classic example of an option embedded in engineering design. It was built with extra strength, which gave the owners the "option" to double-deck the bridge if the conditions were ever appropriate. The owners were not obliged to add to these structures, let alone at a particular time. They could do so when appropriate, if ever.

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 in the context of this discussion, however, 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 a bridge.

Types of Options

It is useful to distinguish among three versions of options:

- Financial options;
- Real options "on" projects, focused on accelerating or deferring projects; and
- Real options "in" engineering systems, focused on optimizing the technical design.

This paper focuses on optimizing the technical configuration of the deployment of a system.

Financial options are the most common. They involve financial contracts in which one group sells to another the ability to execute a future transaction. A financial option ordinarily gives the holder the right to acquire some asset (e.g., company shares, barrels of oil, foreign exchange) at a fixed price over some time. Such options are routinely traded in financial markets involving 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 (*4*). Most discussions of these options treat the technology itself as a figurative black box. In general, they refer to the owners' capability to open or close a facility or to defer the construction or expansion of a project. Brand et al. (*5*), Mehndiratta et al. (*6*), Chu and Polzin (*7*), and Chiara and Garvin (*8*) discussed this approach in the context of transportation. These options that do not involve design issues can be referred to as real options "on" projects.

The options particularly interesting to system designers involve specific features or configurations of design. These are called real options "in" systems (*9–11*). The George Washington Bridge had such options. Its design involved extra steel and strength that enabled various forms of expansion. This flexibility in the system existed only because the designers had taken special steps to provide it. Similarly, the development of ITS, in which choices have to be made concerning the design of the systems, can involve real options "in" systems.

Reasons to Use Options

Options enable 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 by taking advantage of new opportunities.

Options enable system managers to control risks and exploit opportunities. 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, or they may be somewhere in between.

Option Value Created by Uncertainty

The value of an option increases with uncertainty. This is a remarkable phenomenon, often counterintuitive. 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 is, the more the option is worth.

The value of flexibility derives from our uncertainty about what is the best thing to do. If there were no uncertainty, we would do the right thing now and be done with it. Uncertainty creates the value of the option. As with the George Washington Bridge, the real option "in" the system made it possible to avoid making a wrong choice (avoiding a loss is good) and making the right choice when it became apparent what that would be (another good), while deferring capital investment (yet more good). In general, the greater the uncertainty in the underlying driver of value is, the greater the value of flexibility is.

Because real options are most valuable when the future is uncertain, they are especially valuable for large-scale, innovative, long-term

developments such as ITS. Such projects can 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, the flexibility must be valued to compare it with these costs.

REAL OPTIONS VALUATION

There are three practical approaches to the valuation of flexibility in system design:

- Decision analysis,
- Simulation, and
- A hybrid of decision analysis and simulation.

The choice between them depends on the situation, as Chambers indicated (*12*).

System designers can easily use decision analysis to deal with many uncertainties, particularly discrete, "go–no go" possibilities (e.g., the government will or will not enter the market) that are otherwise difficult to investigate. As Ramirez (*13*) demonstrated, decision analysis thus permits a feasible approach in many important cases beyond the reach of conventional options analysis.

Simulation offers an effective way to handle uncertainties with complex distributions around a variety of 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. Simulation has been successfully used to evaluate flexibility in many contexts (*14–16*).

The hybrid approach combines decision analysis for those parts, such as the research and development process, that feature multiple discrete uncertainties and simulation for aspects that diffuse continuously over time, such as market penetration of a product (*17*). A hybrid analysis is most practical for complex systems that incorporate a wide range of uncertainties that cannot conveniently be handled by a single method. An application to a case study of an ITS system is discussed below.

CASE STUDY: DESCRIPTION OF ITS APPLICATION

To illustrate how a flexible approach to system design and deployment can increase its expected value, an application in ITS was examined. 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. Typically, ITS

- 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

ITS 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 (*18*) described, ITS have great potential. Beyond increasing the efficiency of current practices, such as toll collection, ITS could provide important new societal benefits. For example, they could reduce congestion through variable pricing of travel and 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 an ITS poses great challenges and risks. It is usually a partnership between the public sector, which typically provides roadside infrastructure, and the private sector, which provides in-vehicle devices. Effective ITS operations must link these two technologies, which may require considerable cooperation between the public and private sectors. Yet their goals differ. The public sector is interested in creating benefits for the public at large. The private sector, while subscribing to public benefits in general terms, is concerned with either commercial profits or benefits accruing to buyers of the in-vehicle equipment. Moreover, insofar as private users either do not choose to invest in the in-vehicle devices or are not required to do so, 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

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 U.S. National Highway Traffic Safety Administration (NHTSA), automobile vehicles crashes in the United States in 2000 cost $230 billion (*19*). This figure represents the present value of lifetime costs for 41,821 fatalities, 5.3 million nonfatal injuries, and more than 27.5 million damaged vehicles. Even small improvements would have great value.

Intersection Collision Avoidance Systems (ICAS) is the collective name for ITS designed to achieve this purpose. As the U.S. Department of Transportation indicates, ICAS come in three major versions (*20*):

- 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.

Infrastructure autonomous ICAS require large initial investments in infrastructure, generally by the public. Infrastructure is difficult to deploy in small increments in the way that 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 benefit immediately from using intersections equipped with infrastructure autonomous ICAS.

Vehicle-based ICAS have contrasting characteristics. They do not require great investments in infrastructure. Their cost can be carried by private users paying incrementally for OBU, much as they pay for on-board global positioning systems or satellite radio. However,

this system benefits only vehicles equipped with OBU (and secondarily, those into which they do not crash). Thus the effectiveness of vehicle-based ICAS depends directly on the market penetration of the OBU.

Hybrid systems mix these features. 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 almost surely will have some characteristics of both systems.

Diffusion of OBUs

The potential rate of adoption of the in-vehicle devices is a major uncertainty associated with the development of ICAS. 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 diffusion of innovations into the vehicular fleet is inevitably slow. This is because the expected life of a car in the United States in 2007 is approximately 13 years. Thus, any new feature takes a long time to become pervasive in the national fleet. Even if a device is mandated for all new vehicles, it takes approximately 13 years until all cars would be equipped with it, since some cars would last longer than the average. Diffusion can be accelerated when the innovation can be retrofitted on existing vehicles. For example, transponders can be attached to cars for electronic toll collections (ETC). However, even the most optimistic assumptions are that 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 (*21*).

The diffusion of OBU for ETC indicates how slowly such devices penetrate the market. Consider Japan, which has been a leader in this regard. Japanese drivers bought more than 11 million ETC units in 5 years. But these sales translate into only a 20% penetration of the national vehicular fleet (*22*). The adoption of ETC transponders is remarkably slow considering that they are cheap (approximately $20), easy to install, and provide the clear benefit of speeding through toll stations. Some drivers may not use the highways providing ETC; others simply do not bother to install the ETC transponders. In short, the diffusion of OBU is likely to be a slow, uncertain process.

Technical Uncertainties

The performance of any eventual ICAS must be speculative. These systems are still research projects. Their effectiveness in preventing accidents is not yet determined. Moreover, there are many different types of intersection accidents (*23*), and alternative systems will inevitably work better in some conditions than in others. Further, the success of any system depends on its distribution, because the frequency of accidents at intersections varies widely, as Japanese researchers have demonstrated (*24, 25*).

To illustrate the options analysis procedure, the case study used estimates of the short-term probability of success of an ICAS. It assumed that the ICAS could have medium success (probability = 60%), have high success (probability = 30%), or fail (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.

The analysis also assumed that the market penetration of the OBU depends on the success of the ICAS—people are more likely to adopt the technology if it performs well. The analysis assumed that if the research and development were highly successful, the adoption rate would be either fast (probability = 80%) or slow (probability = 20%). If the research and development had medium success, it was assumed that these probabilities were reversed.

CASE STUDY: BASE-CASE ANALYSIS

The base case is a standard benefit–cost analysis. It provides the norm that demonstrates the benefits of the options analysis. It calculates the value of the decision to commit to the development of the ICAS. For illustration purposes, the analysis valued the OBU technology that requires the least public expenditure and simultaneously appears to maximize the private participation in the deployment of ICAS, through the purchase and installation of the OBU.

The standard approach focuses on the most likely outcome. In this case, this would be that the research and development process would have medium success leading to a net present value of $2.3 billion (Table 1). Because this result depends on debatable assumptions, it is neither claimed that this is a solid estimate of the benefits of the OBU-based ICAS technology nor presented that this is a basis for investment decisions. Yet this estimate is not unreasonable. Because intersection collisions cost approximately $230 billion a year, even a minimally successful ICAS system could be worthwhile.

Note that standard valuations focus on a single, most-likely flow of benefits. They neither indicate the risks nor the opportunities. Thus the $2.3-billion valuation both hides the possible failure and underestimates the possible great value of the system if all works well.

CASE STUDY: OPTION ANALYSIS

Investing in research and development creates options. If the research and development is successful, it creates the right, but not the obligation to implement the system. System managers can then decide if it is worthwhile to do so. Sometimes it will not be advisable to deploy a system, even if the research and development is successful. The costs may be too high compared with the benefits, for example, if a competitive technology offers better value.

Investing in research and development to create an option—and leaving the subsequent development open—is fundamentally different from committing to the system from the start. Buying only the research and development is inexpensive compared with the deployment of the system. Also, it provides the flexibility to walk away from the system if it appears insufficiently worthwhile. This may occur either because the benefits of the system do not compensate for its

TABLE 1 Summary of Net Present Values Associated with Each Scenario for ICAS with On-Board Units

Research and Development Outcome	OBU Market Penetration	Net Present Value ($ billions)
Good	Fast	17.4
	Slow	6.29
Medium	Fast	7.50
	Slow	2.30

costs, given the then-current market conditions, or because the research is not paying off fast enough.

The recommended procedure for analyzing the value of flexibility of technological systems merges two approaches. This hybrid approach combines a lattice analysis (*26*) with a decision analysis. This approach applies each to the uncertainty for which it is most suited (*17*).

Lattice analysis is widely used to analyze financial options. It examines possible future states for a process that varies around a long-term trend, such as may occur for prices for stocks. These processes exist in some parts of complex systems; for example, the growth in demand for services.

However, many system uncertainties are not steady evolutions following a smooth distribution. In general, the development of an engineering system has to deal with a collection of discrete go–no go, jump uncertainties. For example, it has to deal with such questions as:

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

A lattice analysis is not the right way to model these risks.

Decision analysis is the better way to investigate the implications of the jump uncertainties that characterize many technological systems. It is inherently discrete. It is thus a good way to consider uncertainties associated of ICAS research.

Lattice Analysis

A lattice analysis projects forward, usually with a binomial process, the broadening range of possible outcomes that could develop from a starting point. Thus from the starting point, say a given level of traffic, traffic might increase or decrease; then from either of those two possible outcomes, traffic could further increase or decrease. The lattice is calibrated to maintain the characteristics of the process being modeled; that is, to replicate its trend and standard deviation.

This lattice analysis for ICAS shows that the eventual benefits could become very large, approximately $2 billion/year, in keeping with the possibility that it successfully reduces the losses from vehicle crashes. Conversely, it reflects the substantial uncertainty, as expected.

Lattice analyses were performed for each of the discrete uncertainties considered in the decision analysis. Expected value was calculated for each year, these sums were discounted to the present and summed, and the estimated net present value associated with each scenario was obtained. Hodota (*27*) gives details on these and other calculations for the case study. Table 1 summarizes the results.

Decision Analysis

The complete hybrid analysis uses the lattice analysis in the decision analysis. For the ICAS case, it values the possible outcomes for each of the four scenarios resulting from discrete uncertainties regarding the success of the research and the speed of market penetration of the OBU. Figure 2 illustrates this process. It shows the possible consequences of deciding to proceed with research and development for the ICAS, of observing the results after a first phase, and 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.

The expected net present value of investing in the OBU-based ICAS is as follows: expected value of decision = $6.7 billion = Σ (probability of research outcomes) Σ (probability of penetration) (outcome).

The great increase from the $2.3 billion of the base case is because of two factors:

- Great upside potential if the research and development is highly successful, even if this is not likely, and
- Limited downside, represented by the write-off of the investment in the research and development process.

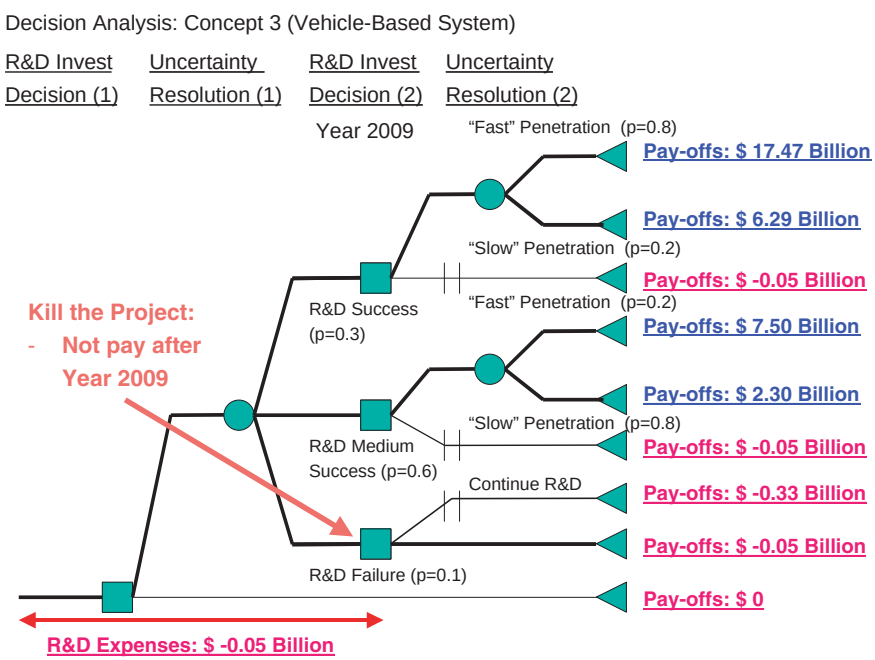

FIGURE 2 Decision tree for ICAS with on-board units, combining results of lattice analysis. (R&D = research and development.)

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

- It is worthwhile to invest in the research and development for the ICAS because the potential value of the system is very large and
- It is important, however, to recognize that the project is risky, and so to be flexible about continuing the process if the research and development 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.

Value at Risk and Gain

The value-at-risk-and-gain (VARG) curve for the commitment to research and development, that is, the cumulative distribution of the possible outcomes, is shown in Figure 3. It illustrates the possibility of reasonable value in general, with some chance of very great gains. The possible loss is confined to the write-off of the research and development 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 research and development and leaving open the possibility of walking away from the project—is the value-added compared with the base case that commits to the ICAS from the start.

Flexibility triples the value of the project in this case. The $6.7 billion in expected value, when considering both the possible upside potential and the ability to walk away from the project, is considerably above the value estimated using a standard benefit–cost analysis (*28*). Such large increases in value are typical of a real options approach to systems design, as numerous case studies indicate (*9*, *14–16*).

POLICY IMPLICATIONS

Interesting policy implications flow from the analysis. Although the numbers used are debatable, they highlight some ideas worth considering:

- Size of the prize. The savings that might be achieved through an effective ICAS are so large (current losses estimated at $230) that significant research and development efforts should be made. It would appear irresponsible not to investigate this opportunity, even though its outcome is 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 because of the huge current losses from intersection crashes.
- Success is not assured. It is entirely possible that it may not be possible to develop workable, reliable ICAS.

Thus, a commitment to deployment is premature. Given the possibility of failure, it would be foolish to commit to implement any ICAS until more is known. The bottom line is that it would be good policy to invest in ICAS research and development to create the option for eventual implementation of ICAS. The research and development results should be reviewed after a reasonable period to determine whether the project should continue. Put another way, the right way to go is an aggressive research and development program limited by a sunset provision.

CONCLUSIONS

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

- Take advantage of opportunities—to develop the system if the research and development is successful—and
- Avoid bad situations—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.

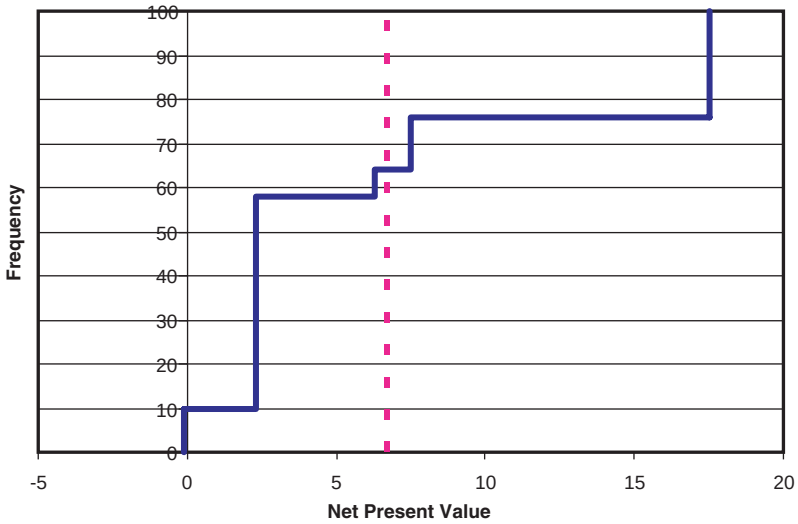

FIGURE 3 Value at risk and gain for the investment in research and development of OBU-based ICAS.

The case study 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. 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, whereas the lattice analysis provides a good basis for considering gradually evolving situations.

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