NPS-GSBPP-16-003

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

CASE: REAL OPTIONS IN DEFENSE R&D

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November 2016

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Prepared for: Naval Postgraduate School

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YYYY)***
30-11-2016

2. REPORT TYPE
Technical Report

3. DATES COVERED ***(From-To)***
01-09-2016 to 30-11-2016

4. TITLE AND SUBTITLE
Case: Real Options in Defense R&D

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Menichini, Amilcar A.
Celiktas, Mehmet

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)
Graduate School of Business and Public Policy
Naval Postgraduate School
Monterey, CA 93943

8. PERFORMING ORGANIZATION REPORT NUMBER
NPS-GSBPP-16-003

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This case uses investments in Defense R&D to help students understand the importance of real options in capital budgeting. Real options allow decision makers to incorporate managerial flexibility into investments projects by providing them with choices under uncertain and risky conditions. This case is intended for courses in managerial finance.

15. SUBJECT TERMS
teaching case; real options; defense R&D; capital budgeting; net present value

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			
Unclassified	Unclassified	Unclassified	UU	29	Amilcar A. Menichini
					19b. TELEPHONE NUMBER *(include area code)* 831-656-2694

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

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NAVAL POSTGRADUATE SCHOOL
Monterey, California 93943-5000

The report entitled *"Case: Real Options in Defense R&D"* was prepared for the Naval Postgraduate School.

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CASE: REAL OPTIONS IN DEFENSE R&D[1]

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[1] This case was developed and written by Professor Amilcar A. Menichini and Captain Mehmet Celiktas. Amilcar A. Menichini is an Assistant Professor of Finance at the Naval Postgraduate School's Graduate School of Business and Public Policy and Mehmet Celiktas is a Captain of the Turkish Army. The information in this case is based on public documents and is not intended as a source of primary data; it was developed solely to facilitate classroom discussion.

CASE: REAL OPTIONS IN DEFENSE R&D

Countries invest in defense research and development (R&D) projects to enhance their military capabilities (Mowery, 2010). The motivation behind defense R&D may include national security, global military competition, or even potential economic profits (Hartley, 2011; Mowery, 2010). Regardless of the expected benefits, the success of defense R&D projects depends highly on the scientific and technological infrastructure and the human capital of the respective country. Nevertheless, one very important issue that affects the overall success of defense R&D investment is the selection of the R&D project with the best potential outcome. Considering the limited resources as well as increasing accountability, transparency, and efficiency concerns, picking the best R&D project becomes an extremely important step for defense managers.

Bearing in mind that defense R&D is a risky undertaking as the final outcome is uncertain, decision makers should incorporate flexibility into investment decisions. Popular valuation methods (e.g., net present value, also known as NPV), however, ignore the value of flexibility that can be attained by real options—e.g., the options to defer, abandon, and expand. The integration of relevant real options into the project evaluation process improves the net worth of R&D projects and helps decision makers benefit from uncertainties.

1. DEFENSE R&D

1.1. Definition and Data

An internationally recognized definition of research and development is provided by the Frascati Manual[2], whose aim is to provide countries with standard concepts and statistical practices to measure and compare R&D activities across nations (OECD, 2015). According to the manual, R&D[3] "comprise[s] creative and systematic work undertaken in order to increase the stock of knowledge—including knowledge of humankind, culture and society—and to devise new applications of available knowledge" (OECD, 2015, p. 44). The Frascati Manual groups R&D activity into three elements:

[2] The Frascati Manual was drafted by the Organization for Economic Co-operation and Development (OECD) nations in 1963, and revised in 2002 and 2015. The Manual is "the de facto R&D reference document across countries" (OECD, 2015, p. 22).

[3] The Frascati Manual adopts the term "research and experimental development" rather than "research and development (R&D);" however, it uses them interchangeably.

“basic research, applied research, and experimental development” (OECD, 2015, p. 45). The manual further defines five “must-have” criteria for R&D activities:

- novel [focused on new discoveries],
- creative [built on innovative ideas and hypotheses],
- uncertain [final outcome is unclear],
- systematic [planned and budgeted],
- transferable and/or reproducible. (p. 45)

According to the Frascati Manual, “all five criteria are to be met, at least in principle, every time an R&D activity is undertaken whether on a continuous or occasional basis” (OECD, 2015, p. 45). Therefore, the objective of R&D—whether basic research, applied research, or experimental development—is to find tangible discoveries that add on current knowledge by utilizing creativity with a systematic approach in an uncertain environment. The manual lacks a definition of defense R&D; however, defense R&D can be thought of as the R&D activities performed by the military. In this sense, defense R&D adopts the Frascati definition, and its five must-have criteria, for the activities that contribute to the military output.

Although a standard manual is established for R&D concepts and statistics, the published defense R&D data have some important problems including the exclusion of privately funded defense R&D, secrecy issues related to national security, long-range program durations, and the lack of reliable measurement for the final output of an R&D project. OECD (2016) also admits the difficulty of estimating defense R&D data that are consistent with the Frascati Manual. Despite these limitations, comparable defense R&D data can be gathered from the OECD.Stat (2016a, 2016b) database. Detailed defense R&D data for OECD countries for the years between 2010 and 2015 are in Table 1 and Table 2.

1.2. Importance and Challenges

Defense R&D has several benefits for the respective country in preserving national security, deterring potential adversaries, leveraging the competitive position, and providing economic benefits. Primarily, developing critical defense capabilities and national weapon systems is extremely crucial for a country's national security (Jang & Lee, 2010). Countries improve their capacity to eliminate any threats from potential adversaries provided they maintain technological superiority and competitive military power through constant enhancement of its state-of-the-art military capabilities. Several historical examples illustrate how technological advances in defense have improved the national security and changed the course of conflicts, such as the atomic bomb, the jet engine, satellite technology, and the space probe (Hermann, 2008).

Defense R&D aims at expanding the boundaries of defense technology and capabilities to respond to future military requirements and cope with global competition. In this regard, defense R&D is part of a country's long-term strategy rather than a means of satisfying immediate needs. The way the previously mentioned technological breakthroughs developed demonstrates that advanced military capability not only ensures national security but also provides deterrence by fostering prestige and veneration. The country that possesses the latest military technology—the longest range, the highest precision, the most destructive, or the lowest margin of error—gains substantial power to shape world politics. Moreover, since these capabilities are transferrable, and expensive, they provide the country with extraordinary economic benefits when traded to other countries that demand these capabilities (Hartley, 2011).

However, there are several challenges with defense R&D that make decision making and capital budgeting extremely difficult. These challenges—which are mainly attributable to the nature of the R&D project—include its uniqueness, long project life, uncertain outcomes, and risks and uncertainties regarding the research and development process. First, since an R&D project is one of a kind, opportunities for developing models and procedures for evaluation and improvement are limited (Ceylan & Ford, 2002). For instance, the U.S. Department of Defense (DOD) Assistant Secretary of Defense for Research and Engineering (ASD [R&E]) Strategic Guidance states that the DOD has around 10,000 unique R&D projects decomposed into 17 distinct portfolios ranging from biomedical to space (2014). This wide range and exclusive nature of defense R&D prevents decision makers from gathering historical data and creating empirical standards, thereby making forecasts and plans under uncertainty very demanding.

Second, due to long project durations, conditions observed before the start of the project may change (Ceylan & Ford, 2002; Keat, 2012). The timeframe for a defense R&D project from initial planning to deployment is 10–25 years (Parnell, Jackson, Burk, Lehmkuhl, & Engelbrecht, 1999). An example that illustrates this duration is the Eurofighter Typhoon project, which lasted 18 years (Hartley, 2011). This extraordinarily long project life implies that optimal decisions at the start of the R&D project may become obsolete during the following phases.

Third, evaluating the effectiveness of R&D projects and measuring the defense R&D output accurately and reliably are complicated tasks (Hartley, 2011; Keat, 2012). Expected returns on R&D projects can be characterized by the value they add to the strategic aims of the country, which are generally intangible. For instance, DOD defines three principles for engaging in R&D activities: eliminating threats to national security, providing affordable military capabilities, and technologically surprising adversaries (ASD [R&E], 2014). Therefore, an R&D project for the United States is valuable to the extent that it adds value to these principles, which are extremely difficult to measure. Furthermore, combinations among individual project components add to the project uncertainty, thereby making the measurement of the outcomes more challenging (Ceylan & Ford, 2002; Hartley, 2011). R&D projects, unlike simple procurement processes, are composed of separate elements, all of which are mutually dependent. In fact, defense R&D projects are becoming even more and more integrated in nature in order to synchronize operations in every domain—namely ground, sea, air, space, and cyber (Third Offset, 2016). Therefore, measuring the real worth of defense R&D projects and making decisions are becoming more difficult than ever.

Another aspect of defense R&D that makes measurement more challenging is its spill-over effect (Okur, 2013). Military R&D projects—whether by their process or their outcome—largely influence civilian innovation and may have a substantial effect on the overall well-being of humans (Mowery, 2010). A well-known example is the U.S. Defense Advanced Research Projects Agency’s (DARPA) Advanced Research Projects Agency Network (ARPANET). Initially a communications network based on digital protocols, ARPANET became the foundation of the Internet, which has a dramatic effect on the lives of people (“Paving the Way,” n.d.). Since it is generally beyond the foresight of decision makers, this spill-over effect is an issue in measuring project outcomes, thus adding to the challenges associated with defense R&D project evaluation.

Finally, the characteristics of defense R&D that focus on innovation for future needs and exploration of the unknown, involve extraordinary risks and uncertainties. The global competitive environment and the increasingly complicated nature of new military capabilities also increase these uncertainties (Third Offset, 2016). Moreover, the success of defense R&D projects is extremely dependent on the innovative capabilities of human capital, which is another type of risk affecting the R&D process. All these uncertainties and risks related to defense R&D have a direct effect on the success of the projects. These risks, however, are mostly project-specific, or private, risks—which are the risks that are specific to the R&D project or to the agency conducting the project (Smith & McCardle, 1998; Steffens & Douglas, 2007). These project-specific risks significantly influence the R&D outcome and the success of the project. One may argue that market, or public, risks also influence an R&D project. This argument may sound logical, but it is very limited since there is no market that affects the R&D project directly or indirectly. Market risks, though, should not be confused with external factors that affect the course of the R&D project. External factors may change the project preferences, or in some instances, the success of the R&D activity. For instance, if a nuclear threat occurs, R&D efforts may shift to countering this threat by focusing on innovation on protective gears. Relatedly, sometimes the success of the R&D project may depend on the outcome of an adversary's R&D project that can be assessed in the future. These external uncertainties and risks, however, should still be regarded as project-specific risks, because they can be overcome with internal capabilities, such as capacity of the scientists, the technological background possessed by the agency, and many other private factors. In this regard, project-specific risks affect the course of the R&D tremendously, and they should be dealt with when evaluating the projects.

1.3. Evaluation Methods: Problems and Proposed Solution

Despite the current defense environment, and the characteristics and challenges associated with defense R&D, decision makers still use traditional methods to evaluate defense R&D projects (Ceylan & Ford, 2002; Glaros, 2003). For instance, DOD uses the

Planning, Programming, and Budgeting System (PPBS), which was introduced in 1960s and has been used to construct defense budget in a program-oriented, long-term fashion (DOD, 2013). The PPBS, like other traditional methods, fails to evaluate the real value of the investment in an uncertain environment in that it does not incorporate the value of flexibility (Glaros, 2003).

When choosing among otherwise equal R&D projects, the net present value (NPV) is observed to be the most commonly used traditional method (Brealey, Myers, & Allen, 2008; Trigeorgis, 1996). The NPV method discounts future expected benefits and calculates the present value of the project with a discount rate adjusted to account for the risk of the project (Newton, Paxson, & Widdicks, 2004). In this sense, the NPV assigns the decision maker a passive role in that it does not provide the managers with flexibility to modify their decisions based on unexpected developments later through the project (Trigeorgis, 1996). The NPV approach assumes that everything will go as planned and ignores potential future decisions regarding the project (Newton et al., 2004). As a result of this deficiency, defense R&D projects are often declined because of systematic undervaluation and negative NPV calculations (Angelis, 2000). One way to circumvent these challenges is to be flexible, which allows planners to adjust their initial decisions as the uncertainties evolve. To do so, decision makers should integrate real options—e.g., options to defer, abandon, and expand—into the defense R&D project evaluation.

As soon as new information becomes available and a better strategy emerges, decision makers think of exercising the real options to avoid potential losses and to benefit from favorable returns. This way of thinking, in which managers regard defense R&D projects as real options, is called “real options thinking.” Scholars have widely recognized the value that real options thinking adds to investment decisions. However, they differ on the appropriate approach to integrate real options into R&D projects. One group favors the real options valuation (ROV) approach, which draws its analogy from financial option pricing models that use market data. Others advocate the use of the decision tree analysis (DTA) approach, claiming that since R&D projects are mainly exposed to private risks, the ROV cannot be used. Considering the characteristics and risks associated with defense R&D projects, the DTA approach suggests a better valuation method for real options in defense R&D projects.

2. REAL OPTIONS

Real options as a term was coined by Myers (1977) in his renowned article. Since then, the real options concept has gotten significant attention from both academics and practitioners, leading to several studies on the idea. Real options can simply be defined as “options to modify projects” (Brealey et al., p. 283). For defense R&D projects, this modification includes deferring, abandoning, and expanding the project as the uncertainties evolve. In essence, capital investments are about options, which are “the right but not the obligation to take some action in the future” (Dixit & Pindyck, 1995, p. 105). In this regard, real options allow decision makers to incorporate managerial flexibility by providing them with choices under uncertain and risky conditions.

Moreover, scholars have discussed that managers should think of investment decisions as real options, in which risks and uncertainties can be addressed appropriately by incorporating managerial flexibility. This approach is called “real options thinking,” which Steffens and Douglas (2007) define as “the managerial flexibility to capitalize on opportunities when they arise and/or to minimize the impact of threats” (p. 58). Real options thinking has great value as a strategic decision-making process in evaluating R&D projects, which are associated with high uncertainty and risk. This approach helps decision makers benefit from risky investments and utilize uncertainties favorably as these uncertainties evolve.

As for the taxonomy, real options are generally named after the specific functions they play and the type of flexibility they provide in the investment decisions (Copeland & Antikarov, 2001). Therefore, there is no specific number of real option types that academics agree on. For instance, Trigeorgis (1996) groups common real options into six categories: option to defer, stage, alter the scale (up or down), abandon, switch, and grow. Benaroch (2001) provides an even more detailed taxonomy by defining 13 different types of real options in technology projects. We define below three types of real options—i.e., option to defer, abandon, and expand.

2.1. Option to Defer

The option to defer, also known as the option to delay or option to wait, gives the decision maker the right to defer the investment decision to learn about future outcomes

(Copeland, Koller, & Murrin, 2000; Trigeorgis, 1996). As opposed to the traditional NPV analysis—which assesses projects as now-or-never investment opportunities—the deferment option gives the decision maker a chance to delay his decision until necessary information is available (Ehrhardt & Brigham, 2010). Delaying the decision and waiting for the right time have value in avoiding unnecessary money outlay, since most of the investments in defense R&D projects are irreversible. Accordingly, the option to defer can be used in defense R&D projects whose success depends on uncontrollable variables that will be resolved in the future.

2.2. Option to Abandon

The option to abandon, also known as the option to sell or option to exit, provides the decision maker with a right to abandon if the project becomes unsuccessful (Copeland et al., 2000; Ehrhardt & Brigham, 2010). Managers may choose to exercise the abandonment option once the project turns out unprofitable with negative NPV. Abandonment includes the liquidation of the project and the sale of assets for salvage value. However, for defense R&D projects, since there is no secondhand market for the projects, this option is generally exercised for no significant value (Brealey et al., 2008). Moreover, the abandonment decision should be made by fully accounting for every possible consequence. Trigerogis (1996) warns that when exercised irrationally, abandonment may lead to the loss of accumulated capabilities, which are extremely important for a country's defense R&D activities. The option to abandon can be used in sequential defense R&D projects, which are designed as successive phases that start after the successful completion of the preceding phase.

2.3. Option to Expand

The option to expand gives the decision maker a right to start with a limited operation scale and expand the project later when the outcomes turn out favorably (Copeland et al., 2000; Trigeorgis, 1996). A typical example includes a pilot, or prototype, project followed by full-scale application if the pilot project proves successful (Benaroch, 2001). In this sense, the option to expand creates future growth opportunities when the initial project becomes successful, and safeguards against extreme losses if the program turns out unfavorably. Accordingly, the option to expand may be exercised in the final phase of defense R&D projects, in which the decision maker chooses to implement the project on a limited scale to test potential outcomes, and based on these outcomes, broaden the application of the project.

3. ALTERNATIVE APPROACHES TO VALUE REAL OPTIONS

Although scholars agree on the importance and benefits of using real options in defense R&D projects, they argue on using different valuation approaches—i.e., the real option valuation (ROV) and the decision tree analysis (DTA). The proponents of the ROV approach propose applying financial option pricing theories to R&D projects. These models hinge on market data to value financial options, thus assuming that the risk associated with the investment corresponds to that of the market. However, as many scholars argue, the market data to work the models are not necessarily present for R&D projects, therefore making the ROV models difficult to apply to defense R&D. Moreover, risks associated with R&D projects are inherent to the specific project and unique in nature; therefore, linking the market risk with that of the project is misleading.

Recognizing the problems with ROV applications in R&D projects, many scholars suggest that the DTA is a better modeling and valuation approach. Commonly used in capital investment decision making, the DTA deals with uncertainty and complexity that several other traditional methods fails to account for. In the DTA approach, the investment decision is constructed as series of decision points and chance events within a hierarchy that spans the lifetime of the project (Trigeorgis, 1996). Decision trees map out all relevant decisions, chance events, associated risks and probabilities, and cash flows in a comprehensible way (Magee, 1964). In this regard, the DTA allows managers to follow multiple decision paths and visualize the project risks and the effects of future decisions on the project. Due to this versatile nature of the DTA, real options can easily be modeled in decision trees. In the DTA approach, the value of real option is calculated as the difference between the net present values of the decision trees with and without the respective option.

As opposed to standard investment decisions, which are made considering the maximization of expected wealth and calculated as the NPV of expected cash flows, the defense R&D is not evaluated in a corporate environment, and is not necessarily aiming at wealth maximization. The main objectives of defense R&D for the country include national security, deterrence, and military competition. As a result, these objectives—or the expected outcomes of defense R&D projects—are generally indicated as non-monetary benefits. Although accurately measuring the defense R&D output in monetary terms is a challenge for decision makers, a significant amount of effort can be made to assess proposed capabilities and cost estimates (Hartley, 2011). To conduct a DTA, the analyst, therefore, should convert all costs and benefits into dollar values, such as the case in cost benefit analysis (Boardman, Greenberg, Vining, & Weimer, 2006). For simplicity and teaching purposes, the cases studied in the following section directly provide the monetary values of these payoffs.

4. CASES ON REAL OPTIONS

Three ongoing DARPA projects, which are characterized by high-risk and high-payoff ("Our Research," n.d.), are selected as cases. To enhance the understanding of the use of real options, these cases are simplified to a limited number of decision nodes and chance events. The background information of the cases is actual unclassified information. However, the problem definition and data, including the monetary values and probabilities, are kept fictional to be in conformity with confidentiality concerns. To calculate the NPV of the defense R&D projects, use an interest rate of 5% as the discount rate.

4.1 CASE 1: OPTION TO DEFER

The first case, DARPA's Communications Under Extreme Radio Frequency (RF) Spectrum Conditions (CommEx) program, demonstrates an option to defer, which provides the holder an option to wait for a certain amount of time until certain uncertainties are resolve. The objective of the CommEx is to enhance the communication of friendly forces within a congested jamming environment by suppressing enemy jamming with "adaptive interference suppression" (Phoel, n.d.). The program is currently in its technology development phase.

4.1.1 Background

DARPA awarded CommEx contracts to BAE Systems Company in 2011 to develop adaptive communication technologies under intense jamming, which blocks the RF receivers of military aircraft (Keller, 2011). The company worked on the project until 2015, when it demonstrated the benefits of the CommEx in a laboratory environment (“Communications Under,” n.d.). Currently, the test and demonstration phase is nearly finalized. The CommEx technology is planned as an upgrade to the Link 16 air-to-air data-exchange network, which is used by several nations (Pellerin, 2016). According to DARPA, the CommEx will fix the vulnerability of the Link 16 network to enemy jamming (Skowronski, 2016). If the program passes the testing phase, the CommEx will be installed on aircraft to upgrade the Link 16 network.

4.1.2 The Problem and the Data

Let us assume the CommEx passed all tests and proved to overcome every possible interference known today. DARPA thinks that the system is ready to be installed on the aircraft fleet for a cost of $145 million. However, let us also assume intelligence is received that an adversary has been developing a jammer that may be capable of blocking the CommEx. The adversary and its allies will start using the new jammer two years from now. According to the program manager, the new jammer will have a 20 percent chance of blocking the CommEx. This means that the CommEx will still communicate, despite the jammer, with an 80 percent chance of success. If the adversary’s jammer blocks the CommEx, the payoff will be −$195 because the CommEx should be detached from the aircraft and subject to further development processes. If the jammer cannot block the CommEx, the payoff will be $240 million.

4.1.3 The Option to Defer

Now assume the program manager wants to wait two years and see the capabilities of the adversary’s jammer. After evaluating the jammer, he will decide whether to insert the CommEx. BAE Systems agrees to install the CommEx two years later for a cost of $160 million.

4.1.4 Questions

4.1.4.1 Build the decision tree for the project without the option to defer. Make sure to include all relevant decisions and chance events. What is the net present value of the CommEx project without the deferment option? What is the optimal decision today for the program manager?

4.1.4.2 Now integrate the option to defer and build the decision tree with the real option. What is the net present value of the project with the deferment option? What is the optimal decision for the program manager now?

4.1.4.3 What is the value of the option to defer? What effects did this option have on the project?

4.2 CASE 2: OPTION TO ABANDON

The second case, DARPA's Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) project, illustrates an option to abandon, which is very typical in sequential defense R&D projects. The ACTUV program develops an unmanned vessel that is capable of tracking diesel electric submarines in open seas (Littlefield, n.d.). The prototype vessel is currently being tested by DARPA.

4.2.1 Background

The ACTUV program started in 2010 (Cahn, 2016) and was planned as four consecutive phases: concept exploration, design, construction, and testing (Walsh, 2016). The contractor of the program, Leidos Inc., designed and built the ACTUV as a 132 foot long trimaran, which is required to traverse long distances across the ocean without any maintenance or crew member on board (Cahn, 2016; Walsh, 2016). The ACTUV, also called as the Sea Hunter, was christened on April 7, 2016, the date that signifies the start of the two-year long testing period ("Enjoy the Silence," 2016). As the first milestone of this testing phase, the ACTUV passed all performance objectives, such as speed, balance, maneuverability, and fuel efficiency ("Leidos Completes," 2016). However, the most important aspect of the ACTUV is its unmanned safe navigational capability that is in compliance with the International Regulations for Preventing Collisions at Sea (COLREGs) ("Enjoy the Silence," 2016). Although initially designed for ASW missions, the ACTUV, if COLREGs-compliant, can be extended to other missions, such as mine countermeasures and intelligence (Walsh, 2016). Provided the ACTUV passes the testing phase, DARPA will transfer the program to the Navy.

4.2.2 The Problem and the Data

Let us assume the program manager wants to evaluate the project at the start of the testing phase, on April 2016, to make a decision whether or not to continue testing. If he chooses not to continue testing, the payoff will be $0. If he continues with the testing, the two-year long tests will cost $30 million. Based on his analysis, he identifies three possible outcomes at the end of the two-year testing period. According to the program manager, there is a 60 percent chance that the testing result will be excellent, a 30 percent chance that it will be good, and a 10 percent chance that it will be poor. An excellent result signifies that the ACTUV is flawlessly compliant with the COLREGs, and it can be extended to other missions. The payoff for this outcome is calculated as $50 million. A good result means that, except for some flaws, the ACTUV is compliant with the COLREGs, and the program can continue for ASW missions, but cannot be extended to other missions. The payoff for this chance event is $35 million. Finally, a poor result indicates that the program has significant flaws, which stem from its design and construction. In this case, DARPA should revise the design and construction of the ACTUV, incur additional money outlay, and require several more years for the program to mature. The payoff is calculated as −$90 million.

4.2.3 The Option to Abandon

Consider the program manager wants to secure a contract that allows DARPA to abandon the project if the test results turn out to be poor. Rather than bearing the additional burden in the worst possible outcome, DARPA will choose to terminate the program.

4.2.4 Questions

4.2.4.1 Build the decision tree for the project without the option to abandon. Make sure to include all relevant decisions and chance events. What is the net present value of the ACTUV project without the abandonment option? What is the optimal decision today for the program manager?

4.2.4.2 Now integrate the option to abandon and build the decision tree with the real option. What is the net present value of the project with the abandonment option? What is the optimal decision for the program manager now?

4.2.4.3 What is the value of the option to abandon? What effects did this option have on the project?

4.3 CASE 3: OPTION TO EXPAND

The third case, DARPA's Aircrew Labor In-Cockpit Automation System (ALIAS) program, illustrates an option to expand, which is common in R&D projects whose scale may be increased depending on the outcome of the initial application. The ALIAS devises an adjustable drop-in kit that would decrease the need for onboard crew by providing increased levels of automation to Army helicopters (Patt, n.d.). The ALIAS aims to leverage the existing automation systems to execute a complete mission from takeoff to landing, while increasing mission performance and safety (Patt, n.d.). The program is currently in development phase.

4.3.1 Background

Although the ALIAS program started in 2015—when DARPA awarded a contract to Sikorsky Aircraft Company as the first phase—the technology behind the ALIAS goes back to Sikorsky's autonomous research helicopter launched in 2013 ("DARPA Awards ALIAS," 2015). After making modifications to its technology, Sikorsky demonstrated in May 2016 an autonomous flight of a commercial helicopter controlled by a tablet device ("Sikorsky Successfully," 2016). Following this test, Sikorsky is awarded the second phase of the program, in which the company focuses on enhancing human interfaces and ensuring the transition of the system to additional aircrafts ("Sikorsky Successfully," 2016). The ultimate aim of the project is to transition the ALIAS technology to DOD utility helicopters.

4.3.2 The Problem and the Data

Let us assume that at the end of the second phase, the ALIAS is proved to be transferrable to other utility helicopters. Additionally, the human interface is enhanced to provide an easy to use, safe, and reliable system. The ALIAS is now ready to be installed in the entire helicopter fleet. However, the program manager has suspected that the flight crew, which has had several years' experience with the existing systems, may have low levels of acceptance for the ALIAS. A dramatic change to an automation system may backfire and produce undesirable consequences. The program manager evaluates that the feedback data from the crew will be provided after one year of hands-on experience on several types of aircraft. Consequently, he designates two alternatives: install the ALIAS to either the entire fleet inventory for a cost of $250 million or to one-tenth of the inventory for a cost of $65 million. If the ALIAS is installed to the entire fleet, there is a 70 percent chance that the human acceptance level will be high. In this case, the payoff will be $850 million. However, there is a 30 percent chance that the acceptance level will be low. This means that the technology will not be as beneficial and the payoff will be $300 million. As to the other alternative, where the ALIAS is installed in one-tenth of the fleet, which is a sample of the entire aircraft, the expected human acceptance levels are estimated to be the same. If the acceptance level is high, the payoff will be $100 million. Conversely, if the acceptance level is low, the payoff will be $40 million.

4.3.3 The Option to Expand

Let us assume the program manager wants to secure an expansion contract that allows DARPA to expand the ALIAS to the entire fleet provided the human acceptance level is high. In this case, the DARPA program manager will have an additional decision point where he may choose to expand the program and install the ALIAS technology to the rest of the helicopter fleet. The cost for this expansion will be $200 million. If the program is expanded, human acceptance levels will again be evaluated one year later. This time there is a 90 percent chance that the acceptance level will be high, with a payoff of $1,050 million. There is a 10 percent chance that the level will be low, with a payoff of $300 million.

4.3.4 Questions

4.3.4.1 Build the decision tree for the project without the option to expand. Make sure to include all relevant decisions and chance events. What is the net present value of the ACTUV project without the expansion option? What is the optimal decision today for the program manager?

4.3.4.2 Now integrate the option to expand and build the decision tree with the real option. What is the net present value of the project with the expansion option? What is the optimal decision for the program manager now?

4.3.4.3 What is the value of the option to expand? What effects did this option have on the project?

Table 1. Defense R&D Budgets for OECD Countries, 2010-2015. Source: OECD.Stat (2016a).

Country	2010	2011	2012	2013	2014	2015
Australia	301.4	316.3	298.5	287.6	280.2	292.3
Austria	0.1	0.1	0.1	0.3	1.1	0.3
Belgium	4.9	4.8	4.7	4.6	4.6	..
Canada	273.8	227.6	257.0	233.5	..	..
Chile	..	0.2	0.1	0.2	..	..
Czech Republic	36.4	31.5	29.4	27.5	26.3	25.7
Denmark	9.8	7.4	7.2	7.2	7.6	7.7
Estonia	0.7	0.7	0.8	1.2	3.1	..
Finland	61.8	56.5	55.3	38.9	42.8	37.1
France	2,808.7	1,322.4	1,232.8	1,069.8	1,108.3	1,136.0
Germany	1,449.4	1,165.2	1,135.1	1,133.5	1,152.5	947.0
Greece	2.8	8.0	7.1	5.2	1.4	1.2
Hungary	4.7	0.4	2.0	2.5	1.0	..
Italy	81.2	84.3	78.8	81.7	85.2	..
Japan	1,535.0	883.6	991.6	1,545.8	1,472.0	1,352.2
Korea	2,163.3	2,406.8	2,755.5	2,911.6	2,739.1	..
Netherlands	89.7	86.2	90.4	67.7	67.4	69.1
Norway	104.4	105.0	106.2	107.0	107.3	111.0
Poland	..	..	213.4	163.1	182.1	..
Portugal	6.1	8.3	5.9	5.8	7.3	8.1
Slovak Republic	8.4	12.1	12.6	7.7	7.5	6.9
Slovenia	2.3	1.8	2.2	1.8	0.5	1.0
Spain	164.6	169.2	149.4	114.0	101.0	..
Sweden	248.3	248.5	273.1	135.8	130.7	114.9
Switzerland	14.3	..	15.5	..	18.4	..
Turkey	907.6	888.1	726.0	1,515.3	609.2	911.8
United Kingdom	2,469.7	1,870.0	2,056.2	2,092.9	2,307.5	..
United States	85,346.0	80,361.8	75,678.7	66,099.6	64,985.7	64,419.6

(1) Data are US$ millions, 2010 constant prices and purchasing power parities (PPPs).

(2) Data include defense R&D financed by governments and exclude civilian R&D financed by defense ministries (OECD, 2016).

(3) Data for some countries are missing since they were unable to supply data (OECD, 2016).

(4) Countries, such as Iceland, Ireland, Israel, Luxembourg, Mexico, and New Zealand, are excluded from the table because they had no data or zero R&D budgets.

Table 2. Defense R&D Budgets as Percentage of Total Government R&D Budget for OECD Countries, 2010-2015. Source: OECD.Stat (2016b).

Country	2010	2011	2012	2013	2014	2015
Australia	6.44	6.76	6.58	6.20	6.17	6.62
Austria	0.01	0.00	0.00	0.01	0.04	0.01
Belgium	0.18	0.18	0.17	0.16	0.15	..
Canada	3.23	2.99	3.41	3.14	..	..
Chile	..	0.03	0.02	0.02	0.03	0.02
Czech Republic	2.25	1.70	1.59	1.47	1.41	1.41
Denmark	0.43	0.31	0.31	0.30	0.31	0.32
Estonia	0.35	0.29	0.32	0.46	1.33	..
Finland	2.72	2.55	2.58	1.90	2.14	1.86
France	14.70	6.80	7.12	6.29	6.63	7.18
Germany	5.01	3.95	3.85	3.72	3.85	3.16
Greece	0.29	0.88	0.68	0.42	0.12	0.11
Hungary	0.62	0.06	0.27	0.17	0.15	0.64
Italy	0.66	0.73	0.72	0.79	0.83	..
Japan	4.77	2.64	2.91	4.62	4.42	4.36
Korea	13.27	13.80	14.84	14.78	13.48	..
Netherlands	1.57	1.47	1.67	1.23	1.22	1.22
Norway	4.32	4.34	4.36	4.19	3.98	3.86
Poland	..	..	7.15	5.22	4.77	..
Portugal	0.22	0.30	0.24	0.24	0.29	0.30
Slovak Republic	1.68	1.93	2.24	1.41	1.37	1.28
Slovenia	0.68	0.53	0.74	0.67	0.21	0.40
Spain	1.42	1.67	1.73	1.45	1.26	..
Sweden	7.56	7.80	8.05	4.00	3.75	3.34
Switzerland	0.47	..	0.43	..	0.48	..
Turkey	22.53	20.48	17.51	30.12	13.63	20.99
United Kingdom	18.24	14.48	16.19	15.32	16.85	..
United States	57.29	56.81	54.73	52.71	51.25	50.92
OECD - Total	**28.60**	**26.88**	**25.98**	**23.91**	**23.29**	**..**

(1) Data are percentages.

(2) Data include defense R&D financed by governments and exclude civilian R&D financed by defense ministries divided by total government R&D budget (OECD, 2016).

(3) Data for some countries are missing since they were unable to supply data (OECD, 2016).

(4) Countries, such as Iceland, Ireland, Israel, Luxembourg, Mexico, and New Zealand, are excluded from the table because they had no data or zero R&D budgets.

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