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Article

Real Options Analysis for Acquisition of New Technology: A Case Study of Korea K2 Tank's Powerpack

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Abstract: For sustainable defense management, it is essential to acquire weapons systems that can adapt to future uncertain threats and, at the same time, to invest efficiently with limited budgets. Economic analysis is used to examine the costs, benefits and uncertainties of alternatives. In particular, the use of the real options valuation, which is one of the methodologies of economic analysis, is expanding. The real options valuation has shown effectiveness across various industries to evaluate investment strategies. In this paper, we apply the real options valuation to the weapon systems development case and confirm its usefulness. Unlike previous studies, the real option valuation methodology is applied retroactively to the finished project, compared to existing research mainly applying real options to value research and development (R&D) without knowing how the project completed. We use the following procedure. (1) Define the uncertainties of the three acquisition alternatives (development, technology adoption, and purchase). (2) Calculate the benefits of the three acquisition alternatives with expected and actual data without uncertainties. (3) Model the decision tree without options and with options. (4) Analyze and compare results with benefit and benefit cost ratio. We analyzed the Korea K2 tank powerpack development case by applying real options. We could see that the real options could have reduced the risk of losses when the development risk is high and market uncertainty exists. From the case study of the development of the powerpack, we learned the following three lessons. First, we reaffirmed the importance of objective value analysis in project decision making. Second, we need to analyze the project value continuously and revise the acquisition strategy accordingly. Third, the effectiveness of the real options valuation was confirmed for sustainable defense management. In addition, the real option analysis data acquired from similar finished projects can be useful for establishing a new product acquisition strategy and, at every decision-making phase, the real option evaluation should be continuously performed with updated information. In this paper, we first perform real option valuation of finished weapon systems in the Korean defense field. This paper is valuable in establishing a rational methodology for applying economic analysis to weapon system acquisition projects.

Keywords: sustainable defense management; real options; discounted cash flow; net present value; benefit valuation; K2 tank; powerpack

1. Introduction

Defense projects are different from other industrial projects in at least two important respects. First, defense projects are usually large, complex, and interdisciplinary. Second, they use state-of-the-art technologies to achieve the required operational performance, thus increasing the technology risk involved in their execution [1].

Dealing with the technological risk leads to a variety of analyses to enable decision makers to choose a rational acquisition strategy. Examples are technical forecasting and economic analysis. Technology forecasting activities are carried out on core technologies, and economic analysis is widely used for weapons systems development. Technology forecasting applies systematized knowledge to manage technology efficiently in the future [2,3]. Technology forecasting is an important job for R&D planning and technology strategies in a company. Various methods have been used for this purpose. Daim et al. (2011) compiled and provided technology forecasting papers using information technology [4]. Robinson et al. (2013) proposed a framework using various analysis and tools [5]. Cunningham et al. (2011) used number of papers [6]. Sasaki et al. (2013) used citation data from the Institute for Scientific Information's DB [7]. Jun et al. (2012, 2014) utilized patent information [8,9]. Most companies and nations would like to improve their competitiveness in national defense. Furthermore, they want to sustain the technological competitiveness for national defense [10]. Economic analysis is an umbrella term for any type of analysis examining the costs, benefits and uncertainties of alternative ways of achieving a given objective or fulfilling a need. An economic analysis is a systematic approach to choosing the best method of allocating scarce resources to achieve a given objective. This analytical approach does not replace the judgment of the decision maker, but rather aids and informs the decision [11]. Discount Cash Flow (DCF) is commonly used as an economic analysis technique. In recent years, the real options valuation that converts project decisions into value is spreading [12].

DCF is a useful valuation technique when the occurrence of future cash flows is deterministic, but it is of limited value when there is uncertainty about the business. Various research cases point out that traditional DCF methods may fail to consider the flexibility of a project to revise decisions after a project begins [13–16]. That is, the traditional DCF approach does not capture the realistic valuation of an investment because it does not explicitly account for the value of real options inherent in capital budgeting. Consequently, DCF techniques often fail to provide sound valuation when the business environment is uncertain and forgo the value created by flexibility in management decisions [17–19].

In the real options valuation, uncertainty can sometimes be perceived as an opportunity for an enterprise, because it assesses the value of flexible decision-makings in an uncertain business environment. By using real options, guidance can be provided on a variety of flexible decisions, including whether to implement new projects, or to decide whether to continue, expand, or reduce existing projects. In real options, these decisions have value, and careful decision-making guidelines are provided in that the result of the one made decision is irreversible. In other words, the right decision, which is overlooked in DCF, is interpreted as one option value [20–22].

We applied the real options valuation to the weapons systems development case and confirmed its usefulness in supporting flexible decision-making.

2. Background

The theoretical basis of the real options valuation model has been developed from financial options. Merton (1969) and Black and Scholes (1973) developed a pricing model for financial options from the early 1970s [23,24]. In the 1980s, the real options valuation began to be used for real assets rather than financial assets. Brennan and Schwartz (1985) and McDonald and Siegel (1986) conducted studies on the development of natural resources [25,26]. Since then, Dixit and Pindyck (1994) integrated the various real options theory and application examples developed in the past, so that the real options technique has become more popular in academic and practical fields [20]. In particular, it was actively used as an evaluation tool for R&D project investment [27]. In the 2000s, real options have been used to ensure optimal design options for the system [28,29], which is referred to as real "in" options [30]. In addition, considering all modules constituting a system as an option in an economic sense, Architecture Options (AO) are studied. The purpose of AO is to identify an optimal system architecture in terms of "adaptability attributes" that support recurring, originally unforeseen, upgrades of the system [31,32].

There are various pricing models for estimating the value of options in the real options valuation, which are more complex to calculate than DCF. Real options pricing models include the Black–Scholes model, lattices model, and Monte Carlo simulation. Each pricing model has advantages and limitations, so it is used depending on the characteristics of the analysis target [33,34]. In particular, Monte Carlo simulation is used when the variable is stochastically variable. Scott (1987) examined the pricing of European call options on stocks that have variance rates that change randomly [35]. Boyle et al. (1997) reviewed the Monte Carlo approach and described some recent applications in the finance area [36]. Cheah et al. (2006) applied Monte Carlo simulation for pricing of the Malaysia–Singapore Second Crossing bridge options [37]. Mun (2006) provided a Monte Carlo simulation guide and software [38]. Bashiri et al. (2018) presented the idea of fitting optimal decision making boundaries to optimize the expected value, based on Monte Carlo simulated stochastic processes [39].

The real options valuation has shown effectiveness across various industries to evaluate discrete, long-term investment strategies [40,41]. Recently, Pellegrino et al. (2018) used a real option valuation on the commodity price volatility mitigation in supply chain [42]. Ranieri et al. (2018) developed a real options-based model for comparing technologies that can flexibly cope with organic waste variations in the urban waste management system investment [43]. For reference, it should be emphasized that real option valuation is used for decision making with investments. Habib et al. (2017) optimized future uncertain debris processing, but no investment exists [44]. For analysis of real options in R&D, decision trees in combination with discounted cash flow analysis to determine the current values of future states of the systems are the best available techniques [19,45].

The real option is currently being actively used in the field of defense weapons systems R&D. Naval ships are pursuing modular design to ensure flexibility and adaptability in response to uncertain future threats [46]. Real option valuation is used to analyze the economic value of modularization options. Addler et al. (2007) analyzed the potential benefits of open architecture in the AEGIS software maintenance and upgrade process [47]. Engel and Browing (2008) showed that the adaptability of the system increases its lifetime value [31]. To cope with uncertainties in the future maritime domain, Buurman et al. (2009) also showed that modular designs are worth more than fixed designs [19]. They also used it to select weapons systems application technology [48] and in every decision stage in terms of Weapon System Acquisition management. It can be used to supplement acquisition strategies continuously and actively, using updated information [49,50].

For sustainable defense management [10], it is essential to acquire weapons systems that can adapt to future uncertain threats and, at the same time, to invest efficiently with limited budgets. To this end, it is clear that the real option valuation methodology, which has been verified in various cases, must be applied to weapons systems R&D.

Countries such as Korea desire to build their defense design, development, and production capabilities rather than rely on other countries to provide weapons for its defense. Developing its indigenous capabilities carries much more risk than the purchase of proven foreign weapons systems. A problem facing acquisition decision makers is how to identify and evaluate acquisition strategies that balance the needs of developing indigenous capabilities while also delivering needed capability, through weapons, to the military on schedule and under budget.

3. Acquisition Decisions: The Case of Korea K2 Tank's Powerpack

The K2 Blank Panther is a South Korean battle tank that started development in 1995. The Koreans benchmarked and borrowed ideas from overseas, such as the 120-millimeter gun from Germany, the autoloader from France, the fire control system from France, and the powerpack from Germany. The powerpack is a module of the powertrain. The powerpack contains the engine, transmission, and integrative components and can be easily removed and/or replaced, making maintenance on tanks easier. The powerpack for the K2 is based on the MTU890 v12 diesel engine with 1500 horsepower. It was the domestic design, development, and production of the powerpack that caused significant delays in the K2 program [51]. We use the K2 program to illustrate and explore how real options can inform acquisition decisions.

The Korean Defense Ministry faced three alternatives (listed as A, B, and C) to obtain a powerpack.

A: Develop the Powerpack. There are advantages of the unit cost, life cycle cost, securing the technology and export. However, there is a risk of failure.

- Unit Cost: The powerpack's estimated unit cost if developed is $1.1M (million), whereas the purchased powerpack cost is $1.4M. Therefore, it is expected that the development will gain $0.3M benefit per unit compared to purchased cost. The greater is the quantity of production, the greater the benefit would be.
- Life Cycle Cost: Korea receives several benefits from domestic production such as the ability to easily solve problems or repair powerpacks during field operation. it can speed up equipment operation rate and shorten time for battle readiness by rapid comprehensive logistics support. In addition, in the future, it will be possible to reduce the maintenance cost of weapons systems operation by developing domestic powerpack series through sequencing of self-propelled artillery, landed armored vehicle, etc. According to the Defense Acquisition Program Administration's announcement, the investment effect of the K2 tank development program is $3B (billion) in budget cuts, $800M worth of military power builds, and 5401 jobs creation [52,53]. Of course, this number can vary depending on the quantity of production, but it is clear that there is an additional benefit of domestic development.
- Securing the Technology and Export: When developing a weapons system by introducing core sub-systems or core technologies, the export of the weapons system must be approved by the core technology holder's government. In the worst case, exporting weapons systems may not be possible. To prevent these problems, core technology development is essential. The secured technology can also be used in other fields. For example, Korea was in the process of signing a contract in 2000 to export K9 self-propelled artillery to Turkey. However, MTU, Germany, notified Korea that it cannot approve the export of the K9 engine. Eventually, the problem was resolved, but the Korean government was concerned that the same situation could arise when exporting K2 tanks.
- Risk of Failure: Korea has not developed a high-power, high-reliability powerpack of 1500 horsepower. In addition, the K2 tank would be mass-produced in 2011 with the developed powerpack after completion of development in 2008. Therefore, the development schedule was very tight, and it was very likely that the schedule would not be met. In developed countries, it took more than 10 years to develop a 1500-horsepower engine.

B: Introduce Powerpack Technology. The risk of development can be reduced, but exports are limited.

- Reduce risk of Development: Korea has developed and operated powerpacks of less than 1000 horsepower, but the powerpacks of more than 1000 horsepower have relied on overseas purchase due to lack of technology, high development cost and lack of economic efficiency. Therefore, based on the technology and production capacity accumulated in the 1000-horsepower powerpack, the introduction of 1500-horsepower powerpack technology from overseas countries can greatly enhance the development potential. In addition, domestic production can secure a certain level of 1500-horsepower powerpack technology.
- Export Limit: The introduction of technology can lead to difficulties in exporting such weapons system, e.g., the K9 self-propelled artillery. However, the exports issue would be resolved if the export agreement is specified in the technology-introducing contract or exporting the K2 tank, except for the powerpack.

C: Purchase all Powerpacks. Although the risk of development can be avoided, export and domestic technology securing is limited.

- Avoid Risk: The Korean Ministry of National Defense can secure the powerpack on time for mass production of the K2 tank. It is a good alternative when the quantity of mass production is low and the technical difficulty is high.
- Export Limit and No Technology Securing: As with the introduction of technology, exports can be limited. In addition, because there is no domestic production, even if K2 tank production is increased, there is no benefit in Korea.

The Korea DoD finally decided on Alternative A, to develop the powerpack in 2004 and contracted with developers in 2005.

3.1. Uncertainties

This section describes common uncertainties in the acquisition process of weapons systems.

1. R&D Uncertainty: The following risks are included.
    - Technology Risk: Making a reliable military grade powerpack is a challenging, high technology endeavor. There was no Korean manufacturer with experience in the development of powerpacks. Korean automakers, which have technology to develop engines and transmissions, are not interested in powerpacks because tank powerpacks are not marketable. Consequently, no Korean developer has experience in making tank powerpacks consisting of high-power diesel engines and transmissions.
    - Schedule Risk: The six-year development period is set to meet the production stage of the K2 tank. Developed countries took 10 years to develop the powerpack. It is very likely that the project will be delayed.
    - Project Budget Risk: Government R&D budget is limited. Developers must cover their own costs when development is delayed. This risk must be considered with Schedule Risk.
2. Market Uncertainty:
    - Quantity Risk: The Korean government has a limited budget for weapons systems and defense priorities may shift over time. The attack helicopter, the AH-64 Series (South Korea decided to purchase 36 AH-64E attack helicopters in 2013), is a competitor to the production volume of the K2 tank. A risk is the procurement number of tanks decreases, which would result in the development costs being amortized over fewer tanks, thus a higher per unit cost.

Table 1 shows the R&D risks exist only for the development alternative. The technology introduction alternative has very low risk because it is based on Korea's powerpack development and production technology of less than 1000 horsepower and introduces 1500-horsepower powerpack technology. The purchase alternative has no development risk because a proven powerpack would be purchased from a foreign contractor. A German MTU engine and the RENK transmission were used in the K2 tank development. The market risk is due to externalities to the program and consequently equal among all three alternatives.

Table 1. Uncertainties of Solutions.

Risks	Development		Technology Introduction	Purchase
R&D				
Technology Risk	Engine	High	Very Low	None
	Transmission	High	Very Low	None
Schedule Risk	Engine	High	Very Low	None
	Transmission	High	Very Low	None
Budget Risk	Engine	High	Very Low	None
	Transmission	High	Very Low	None
Market				
Quantity Risk	Engine	Medium	Medium	Medium
	Transmission	Medium	Medium	Medium

3.2. Expected Benefit

We calculated the expected benefit of K2 powerpack development without uncertainties and with uncertainties.

3.2.1. Without Uncertainties

This section analyzes the three alternatives assuming no uncertainty or risk. In the analysis, we use the purchase alternative as the baseline for comparison because it is the riskless alternative. The Korean government planned to produce 680 K2 tanks. Additionally, the K2 program included spares for a total planned procurement. We added 10% for spare parts. Thus, the total powerpack production quantity is 748. In Table 1, the program estimated the unit cost to develop the powerpack (Engine and Transmission) would be $1.1M, which is $0.3M less than the cost to purchase it. Table 2 shows the unit price and quantity.

Table 2. Unit price and quantity.

Acquisition Method	Items	Unit Price ($M)	Domestic Production	Export Production	Total Cost ($M) (All Costs or Benefits Are in the Millions.)
Development	Engine	0.50	680 (748) **	200	
	Transmission	0.60	680 (748)	200	$822.8M
Technology Introduction *	Engine	0.50	680 (748)	-	
	Transmission	0.60	680 (748)	-	$822.8M
Purchase	Engine	0.90	680 (748)	-	
	Transmission	0.50	680 (748)	-	$1047.2M

* Production costs are equal to domestic development. ** Considering the Spare volume of 10%.

The development cost for the powerpack is $53M for the engine and $47M for the transmission. The direct benefit of engine development is $0.4M compared to purchase, and the transmission is minus $0.1M. That is a $0.3M benefit per powerpack. Total direct profit can be obtained by multiplying 748 units, which is the total quantity of production.

In the case of indirect profit, the unit price of the powerpack (engine and transmission) is multiplied by the export quantity and converted to the present value (PV). PV is calculated as follows.

$$PV = \frac{V_1}{(1+r)^n}$$

$$V_1 = \text{value at period 1}$$
$$r = \text{discount rate}$$
$$n = \text{number of periods}$$

We estimate the export quantity to be 200 units based on analogy to Korea's K9 self-propelled artillery, which has been produced since 1999 and has been exported at about 184 units overseas since 2017 (India 100 units, Finland 48 units, Estonia 12 units, and Norway 24 units; we exclude exports to Turkey, because Turkey had imported technology from Korea and produced the K2 tank in Turkey). Assuming that K2 tanks are exported in similar quantities as the K9 self-propelled artillery, more than 200 powerpacks will be exported. After 20 years from the initial mass production, there will be benefits for export. Therefore, applying the social discount rate of 5.5% in Korea, the present value of exports is $75.4M.

In the case of technology introduction and purchase, export is impossible, because it had to be approved by the technology owner's or original manufacturer's government. Of course, although it seems possible to export given the present situation, it was impossible in the initial decision stage.

If we ignore the risks associated with development, then the development alternative has a cost savings of $199.8M over purchasing the powerpacks. Benefits associated with development include obtaining the technology domestically and not relying on foreign contractors to meet Korea's defense needs. Table 3 summarizes the results.

Table 3. Total cost savings over purchasing.

Alternatives ($M)		R&D Cost (A)	Direct Savings Due to Lower Unit Cost (B)	Indirect Savings Due to Export Sales (C)	Total Savings (D = B + C − A)
Development	Engine	53	224.4 = (0.40 − 0.10) × 748	$75.4 = \frac{(1.10\times200)}{(1+0.055)^{20}}$	199.8 = 224.4 + 75.4 − 100
	Transmission	47			
Technology Introduction	Engine	53	224.4 = (0.40 − 0.10) × 748	-	124.4 = 224.4 − 100
	Transmission	47			
Purchase	Engine	-	-	-	-
	Transmission	-	-	-	-

3.2.2. Actual Acquisition Experience versus the Planned Acquisition

This section compares the actual acquisition experience of the K2 tank to what was expected or planned in the beginning of the acquisition program. In Table 4, engine development was successful in 2015, but transmission development was not successful until 2017. The development period of the powerpack was delayed from 6 years to 13 years and developers had to spend an additional $ 89M in the delayed periods. Korea DoD decided to import the powerpack and use it for the first production in 2012. Since then, Korea DoD has decided to use the developed engine and imported transmissions for a second production of the K2 Tank in 2018.

Table 4. Expected value versus actual value.

Uncertainties		Expected Value	Actual Value	Remarks
R&D				
Technology Risk	Engine	80% Success Possibility	100%	Succeed in 2015
	Transmission		0%	Failed in 2017
Schedule Risk	Engine	6 Years (2005–2010)	11 Years (2005–2015)	- First Extension: ~2011 - Second Extension: ~2012
	Transmission		13 Years (2005–2017)	- Third Extension: ~2014 - Delayed: ~2017
Budget Risk	Engine	$53M	$93M = 53M + 8 × 5M	Additional Cost - $ 8M/year
	Transmission	$47M	$96M = 47 + 7 × 7	- $ 7M/year
Market				
Quantity Risk	Engine Transmission	680 Units (748) *	306 Units (331)	K2 Tank Production Plan - First Production: 100 (Until 2015) ** - Second Production: 106 (Until 2020) - Second Production: 106 (Until 2020)

* Considering the Spare volume of 10%. ** Powerpacks were purchased, the original plan was 2012.

We calculated the benefits through the K2 tank development record. Finally, the development of the K2 powerpack was a $59.5M loss compared to the purchasing of the K2 powerpack. The damage can be even bigger considering the partners who invested in advance in preparation for the powerpack mass production.

The developed engine costs $0.4M less than the purchased engine. The production volume was decreased to 206 (221, with 10% spare volume) units because 100 units of powerpacks were imported in 2012 to satisfy the demand from the K2 tank procurement. In addition, the Korean DoD failed to successfully develop the transmission and the Korean DoD decided to abandon domestic production and purchase the transmissions from a foreign contractor. Thus, we calculated the benefits based on 221 engine units except transmission units. As can be seen, Korea DoD actually spent $59.5M more than if they purchased the powerpacks.

In fact, the unit price of developed transmissions is more expensive than the purchased one, so there is no direct cost savings. If the Korean DoD bought transmissions and purchased the engine technology, it could save $35.4M. Table 5 shows the results.

Table 5. Actual Costs.

Alternatives ($M)		**R&D Cost (A)**	**Direct Savings Compared to Purchasing (B)**	**Indirect Savings Due to Export Sales (C), Discount Rate 5.5%**	**Total Savings (D = B + C − A)**
Development	Engine	93	88.4 = 0.40 × 221	$41.1 = \frac{(0.50 \times 200)}{(1+0.055)^{20}}$	−59.5 = 88.4 + 41.1 − 93 − 96
	Transmission	96	-	-	
Technology Introduction *	Engine	53	88.4 = 0.40 − 221	-	35.4 = 88.4 − 53
	Transmission	-	-	-	-
Purchase	Engine	-	-	-	-
	Transmission	-	-	-	-

* Reference for comparison.

3.3. Decision Tree with Real Options

The development of the K2 powerpack ended in failure. Engine development solved major flaws and passed the first product inspection in 2015, but the transmission development did not meet the no-defect criteria for 320 h (9600 km) by 2017. The main cause of failure was reliability, not performance. The Korea Ministry of National Defense, which can no longer delay the deployment of the K2 tanks, decided in February 2018 to import the transmissions from Germany. South Korea has not secured transmission technology, and the possibility of exporting powerpacks has declined. In addition, the K2 program was delayed by three years due to the powerpack. In hindsight, purchasing would have been a better choice.

By applying real options to the powerpack development case, we show how real options can help a stakeholder decide on an acquisition strategy. The real option is used as part of the Decision Tree Model.

3.3.1. Decision Tree Modeling

We analyze the development of powerpack without options and with options.

Powerpack with no Options

Figures 1 and 2 are decision trees for powerpack development. Figure 1 shows the program's planned development of the powerpack over a six-year duration. The rectangle represents the behavior or state, the circle is the uncertainty, and the triangle represents the terminal. Alternative A: Development begins and development progresses for six years. Since then, the development has been successful, and the mass production stage is ongoing. Benefits are calculated according to market uncertainty. R&D uncertainty is 100% probability of success, and market uncertainty indicates that a certain quantity is 100%. R&D uncertainty can be treated as variable, but, in this study, it was used only as a distinction between success and failure. In other words, we did not calculate the expected value due to R&D uncertainty (the probability of success), because the focus of this study is not to increase the probability of success or to find out. Market uncertainty (quantity) means that the probability of occurrence of a specific terminal (triangle) is 100%. The terminal is calculated as a triangular distribution, so there is no need to show several terminals.

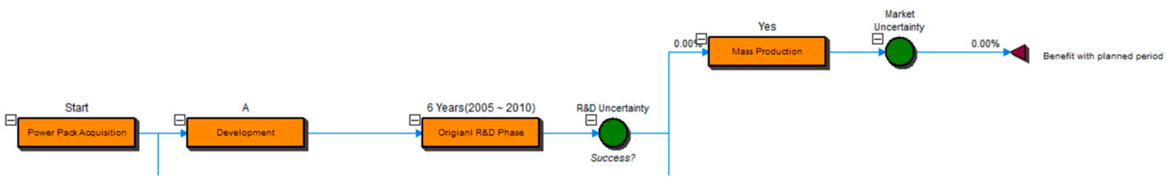

Figure 1. Decision Tree for Development (Planned Period).

Figure 2 shows the program extensions, if the program is unable to develop the powerpack in six years. We assume the program is extended in one-year increments. We have to decide whether to extend the development. The extended development period is expressed as a period from 1 to

10 years. Development periods are listed to facilitate comparison of the benefits of each period. Market uncertainty is the same as in Figure 1.

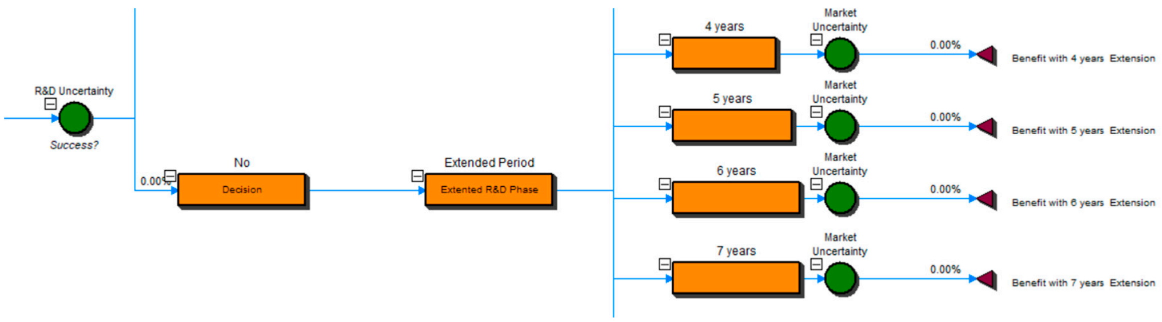

Figure 2. Decision Tree for Development (Extended Period).

Figure 3 is a decision tree for Technology Introduction and Purchase. There is no R&D uncertainty. Technology Introduction has only market uncertainty, which is the same as in Figure 1. The benefit of purchase is constant 0.

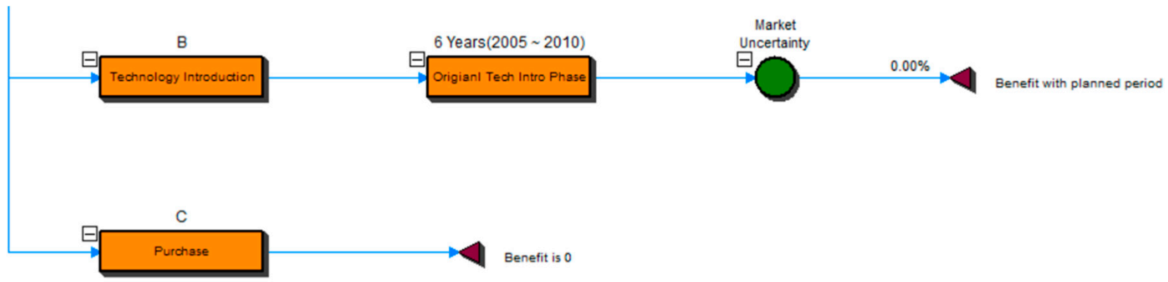

Figure 3. Decision Tree for Technology Introduction and Purchase.

Powerpack with Options

If the powerpack development has already started, it is not easy to abandon the project. Because there is a possibility of success in the future and the Korean DoD will lose the investment cost. Especially in South Korea, only very few cases of weapons development have been stopped. This is due to a culture that does not tolerate failure. Therefore, various options must be considered when establishing an acquisition strategy. Developing all the subsystems necessary for the K2 tank in Korea has advantages of securing the technology, but, if the quantity of production is small, it can be more expensive than purchasing. Even if engines and transmissions are developed domestically, many parts must be purchased overseas. This is because many engine and transmission components are monopolized. Therefore, domestic development for export is a logical contradiction. If Korea cannot export K2 tanks due to the purchased powerpack, K2 tanks can be exported, except without powerpack. Therefore, we can think of the following conditions.

In Figure 4, if the development is not completed during the planned period, the following options are added at Node A.

1. Development and Technology Introduction Options: Purchase engine and transmission technology from overseas. Much development has already been completed. Since it has not solved the major defects, the introduction of technology will make it easier to solve the problems already experienced by developed countries.
2. Reduced Development Option: Produce a lower-reliability powerpack. The failure of Korea's powerpack development project is not due to lack of performance, but due to unreliability of reliability standards. It is an option to introduce a lower-reliability powerpack. Because of the large number of reserves to be prepared for failure, the actual benefit will be less.

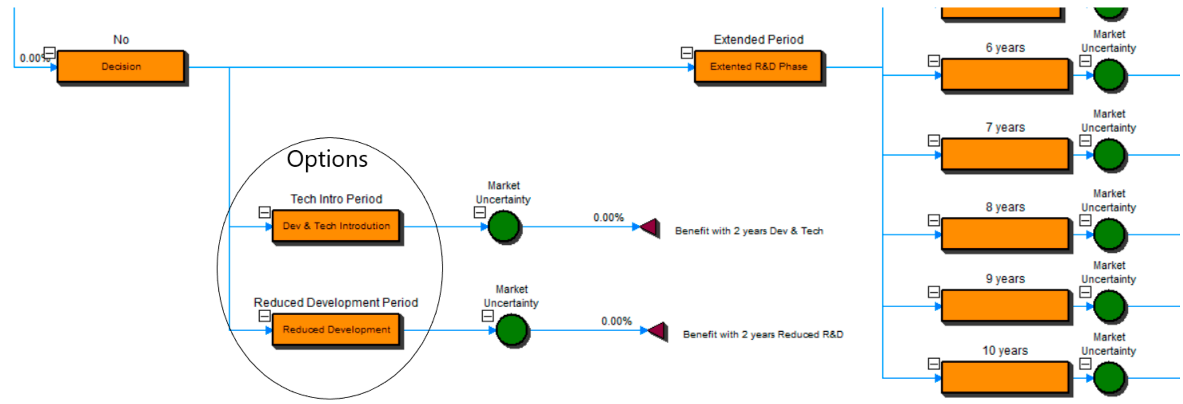

Figure 4. Decision Tree with Options.

3.3.2. Decision Tree Valuation

Each decision tree evaluation was performed under the following conditions.

1. The initial investment in R&D: $100M
2. The additional investment cost for each extension period: $15M/year (max 10 years) (an approximation dividing the development cost of $1M by the planned development period of six years)
3. The quantity: 200–800 units (most likely 400)
4. The export quantity: 50–200 (most likely 100)
5. The reduced rate of domestic production quantity: 20 units/extended year (set the minimum value considering the production capacity of K2 tank is 50 units per year; because produced K2 tanks cannot be operated without a powerpack, the total quantity of powerpacks must be reduced by the number of powerpacks purchased)
6. The reduced rate of export quantity: 5 units/extended year
7. The discount rate: 5.5% [54]
8. Comparisons are performed with NPV (Net Present Value) [55,56]
9. The development and technology introduction option cost: $0M/year, and can be developed within two years because we have already secured development equipment and technical know-how through development; considering the cost of purchasing technology, it was estimated to double the cost of extension
10. The reduced development option cost: $15M/year, which has a benefit of 80% of the base product, and can be developed within two years.

The simulation was performed in the case of completion of the development within the period, the case of the extension of the development period from 1 to 10 years, and the case of the technology introduction. The simulation assumes that the production quantity follows a triangular distribution and Monte Carlo simulation was carried out 10,000 times. Table 6 shows the simulation conditions.

Table 6. Simulation conditions.

Items	Quantity	Development											Technology Introduce	Development and Technology Introduction	Reduced Development
		Extension Years													
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0**	**2**	**2**
Domestic Production	High	800	780	760	740	720	700	680	660	640	620	600	800	760	760
	Medium	400	380	360	340	320	300	280	260	240	220	200	400	360	360
	Small	200	180	160	140	120	100	80	60	40	20	0	200	160	160
	Benefit per unit	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Cost	100	115	130	145	160	175	190	205	220	235	250	100	130	130
	Discount rate	5.50%													
Export	High	200	195	190	185	180	175	170	165	160	155	150	-	-	-
	Medium	100	95	90	85	80	75	70	65	60	55	50	-	-	-
	Small	50	45	40	35	30	25	20	15	10	5	0	-	-	-

4. Results and Analysis

4.1. Powerpack with No Options

Figure 5 shows the simulation result of each case. From the right side, the benefit of planned period and one-year extension, Technology Introduction and 2–5-year extension are plotted. Purchase is 0 vertical line. All benefit is net present value.

In the case of a three-year extension, we can see that it has a lower benefit than the purchase with a probability of about 40%. With five-year extension, the probability of obtaining the benefit is very low.

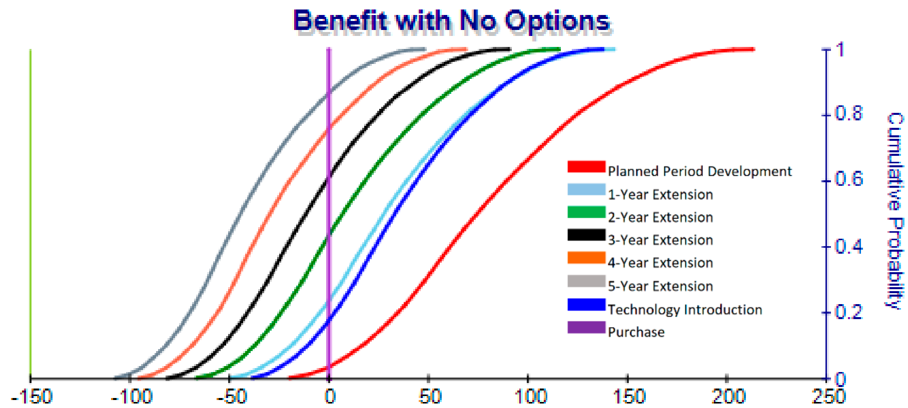

Figure 5. Results of simulation (no options).

In Table 7, if the production quantity is medium, there will be benefits up to two-year extension and the probability of benefit is 60%. If production quantity is high, there will be benefits up to a five-year extension and the probability of benefit is 15%.

In Table 8, if the benefit cost ratio is greater than 1, the project is considered economically viable [57]. Cost-Benefit ratio (B/C) is greater than 1 when project is completed within two-year extension and technology introduction with high quantity production. Considering only the average values, development and technology introduction are not economically feasible.

If the strategy of acquisition is not determined, we can choose the following acquisition strategies (see Table 9).

1. Development: Select when production quantity is high and development is possible within seven years.
2. Purchase: Select when development is expected to take more than eight years, or when production quantity is medium or small.
3. Technology Introduction: Select when production quantity is high and development is expected to take more than seven years.

Table 7. Comparing benefit with no options.

Powerpack Benefit	Development											Technology Introduction
	Extension Year											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0 (Year)**
Min	−19.71	−49.52	−66.54	−81.25	−94.60	−106.65	−116.43	−125.34	−134.12	−140.50	−146.03	−39.54
25% Percentile	38.64	−1.38	−21.12	−38.42	−53.78	−67.74	−79.89	−90.47	−100.80	−108.95	−116.22	5.02
Median	78.41	31.41	9.80	−8.30	−25.52	−42.00	−54.55	−66.89	−77.88	−86.94	−94.86	34.87
Mean	83.81	36.10	14.10	−4.41	−22.21	−38.05	−51.38	−63.81	−74.57	−84.30	−92.38	38.99
75% Percentile	155.36	94.91	69.71	47.23	27.86	10.10	−6.80	−20.73	−34.16	−45.85	−56.60	94.15
Max	213.71	143.05	115.12	90.06	68.69	49.01	29.74	14.14	−0.83	−14.30	−26.79	138.71
0 Benefit Percent	2%	20%	40%	58%	73%	85%	93%	98%	100%	100%	100%	16%
Standard Deviation	49.27	40.41	38.23	36.41	34.50	33.04	31.07	29.65	27.87	26.39	25.14	37.63

Table 8. Comparing B/C with no options.

Powerpack B/C	Development											Technology Introduction
	Extension Year											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**0 (Year)**
Min	−0.21	−0.36	−0.46	−0.54	−0.59	−0.63	−0.65	−0.67	−0.68	−0.69	−0.69	−0.39
25% Percentile	0.38	0.13	−0.05	−0.18	−0.28	−0.35	−0.41	−0.45	−0.48	−0.51	−0.53	0.05
Median	0.78	0.47	0.24	0.05	−0.07	−0.17	−0.24	−0.30	−0.35	−0.39	−0.42	0.36
Mean	0.83	0.51	0.27	0.09	−0.04	−0.14	−0.22	−0.29	−0.33	−0.37	−0.40	0.40
75% Percentile	1.55	1.10	0.77	0.53	0.34	0.19	0.07	−0.02	−0.09	−0.16	−0.21	0.94
Max	2.13	1.59	1.17	0.88	0.65	0.46	0.31	0.20	0.11	0.02	−0.05	1.39
0 B/C Percent	3%	11%	24%	43%	59%	73%	84%	92%	97%	100%	100%	16%
Standard Deviation	0.49	0.41	0.35	0.30	0.26	0.23	0.20	0.18	0.16	0.15	0.13	0.38

Table 9. Acquisition Strategy.

Items	Development Period (Years)										
Quantity	6	7	8	9	10	11	12	13	14	15	16
Low	P	P	P	P	P	P	P	P	P	P	P
Medium	P	P	P	P	P	P	P	P	P	P	P
High	D	D	T	T	T	T	T	T	T	T	T

D, Development; P, Purchase; T, Technology Introduction.

4.2. Powerpack with Options

Figure 6 shows the simulation result with options. From the right side, one-year extension, two-year extension, reduced development option, three-year extension, and development and technology introduction option are plotted. In the case of the reduced development option, we can see that it has a higher benefit than the three-year extension.

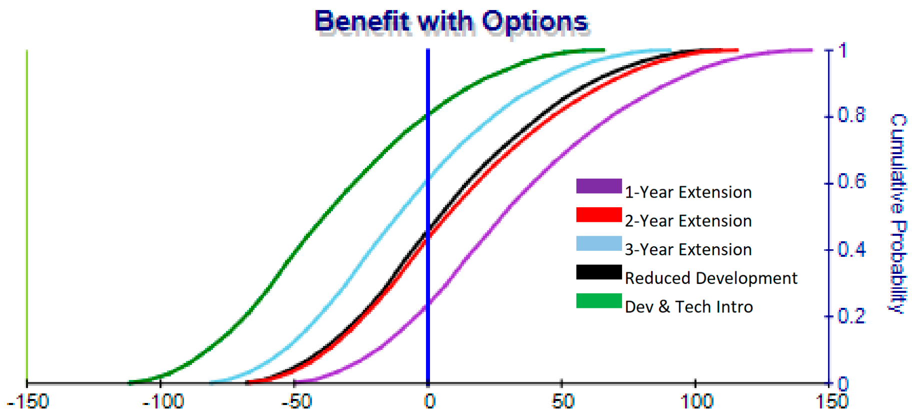

Figure 6. Results of simulation (with options).

In Table 10, through the options, we can complete the project in eight years and expect an average benefit from $11.15M to $36.10M. We can mitigate development risks and losses through our decision. The amount of reduced loss is the value of the real options. If the planned development fails, we can choose the following options.

1. Continue Development: Select when development success potential is very high in two years.
2. The Reduced Development option: Select when development is expected to extend beyond three years.
3. Development and Technology Introduction: Select when the user requires 100% performance and we cannot solve a technical problem and the probability of success is very low.

Table 10. Comparing Benefit with options.

Powerpack Benefit	Extended R&D			Development and Technology Introduction	Reduced Development
	1-Year	2-Year	3-Year	2-Year	2-Year
Min	−49.52	−66.54	−81.25	−110.78	−66.99
25% Percentile	−1.38	−21.12	−38.42	−66.55	−22.95
Median	31.41	9.80	−8.30	−36.78	7.72
Mean	36.10	14.10	−4.41	−32.58	11.15
75% Percentile	94.91	69.71	47.23	21.90	65.14
Max	143.05	115.12	90.06	66.12	109.19
0 Benefit Percent	20%	40%	58%	79%	43%
Standard Deviation	40.41	38.23	36.41	37.51	37.29

The third option is better than the K2 powerpack case. Because the development of the K2 powerpack was delayed by seven years, the transmission failed, and lost $ 59.5M.

5. Discussion

In this case study, the real option valuation methodology was applied to the finished project, while the existing research mainly analyzed the value of R&D by applying real options before development. From the case study of the development of the powerpack, we learned the following lessons.

First, we reaffirmed the importance of objective value analysis in project decision making. The K2 tank powerpack development project was recognized as a project with low development profit and high risk from the start of the project planning. However, the project was carried out in anticipation of localization and export. Korean DoD did not judge the value of project benefit quantitatively, but rather carried out the project by overestimating the social benefit qualitatively. The results of our real options analysis clearly demonstrate this fact.

Second, we need to analyze a project value continuously and revise the strategy. The K2 powerpack development project was not able to do so, even though it had to revise its project strategy according to changes in the external environment and project progress. Based on such changes as delays in development, reduced production of K2 tanks, and purchase of Apache helicopters, the Korean Ministry of National Defense had to consider the transition from development to technology introduction or purchase. In other words, based on updated information at each decision stage, options such as "option to scale", "abandon", and "switch" had to be considered.

Third, the effectiveness of real option valuation was confirmed for sustainable defense management. By adding the Reduced Development option, and the Development and Technology Introduction option, we were able to present a reasonable exit strategy in a project that was delaying development. It is necessary to accumulate rational benefit calculation data that can be used for the benefit analysis of R&D through continuous real option analysis for finished projects. In this way, the real option valuation will be more effective.

In addition, the methodology used in this study can be used not only in the field of defense research and development but also in the field of commercial research and development. This is because general product acquisition strategies are development, technology introduction (or patent license purchase), and purchase (or lease). If the expected final product quantity is highly volatile, the process shown in Figure 7 can be used to valuate options benefit for establishing a new product acquisition strategy. The real option analysis data acquired from similar finished projects can be useful for establishing a new product acquisition strategy and at every decision-making phase, the real option evaluation should be continuously performed with updated information.

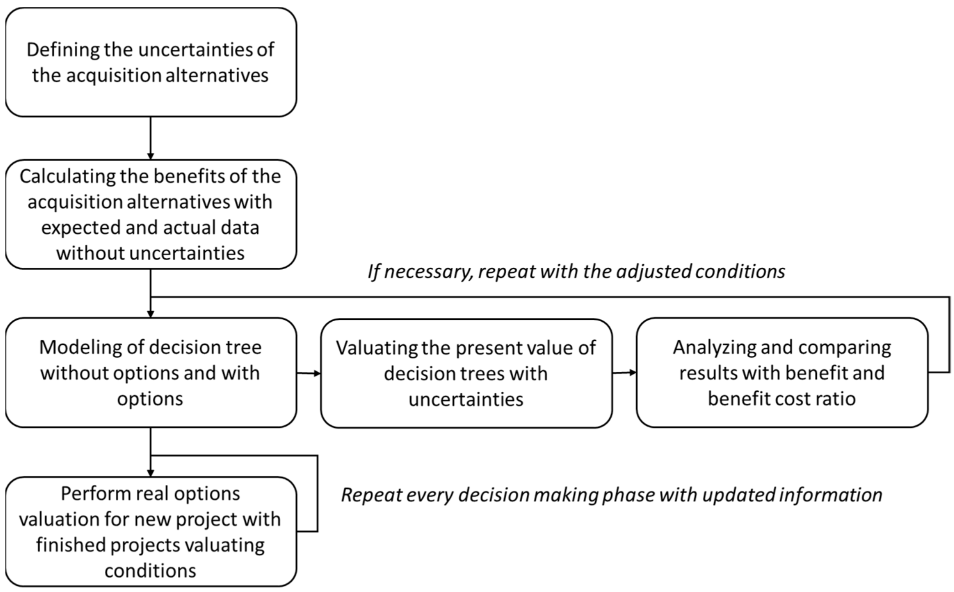

Figure 7. Procedure of real options valuation for establishing new product acquisition strategy.

In Korea, most public investment projects are conducted through cost–benefit analysis, while cost-effectiveness analysis is mainly applied to weapon systems acquisition projects. Cost–benefit analysis has yet to be applied. The cost–benefit analysis seeks to maximize social net benefits by measuring the costs and benefits of the entire population, however applying the social cost–benefit analysis when generating costs and benefits for limited users or producers, such as acquiring weapon systems, is somewhat limited. In this paper, we first performed real option valuation including the cost–benefit analysis of finished weapon systems in the Korean defense field. In addition, this paper is valuable in establishing a rational methodology for applying economic analysis to weapon systems acquisition projects. The contributions of this paper are summarized in Table 11.

Table 11. Contribution table in defense field.

Approach	Analysis Target	Economic Analysis	Flexibility with Uncertainty	Decision-Making Support	Exit Strategy in a Project
Old	• New R&D Project	N/A (only cost-effectiveness analysis)	N/A	• Limited (only initial phase)	N/A
New (in this paper)	• Finished R&D Project • New R&D Project	• Net Present Value • Cost–benefit analysis • Real Option Valuation	• Available	• Every decision making phase	• Available

6. Conclusions

We analyzed the K2 tank powerpack development case by applying real options. We could see that the real options reduced the risk of failure and losses when the development risk is high and market uncertainty exists. We compared powerpack development, technology introduction, and purchasing solution. Monte Carlo simulation was performed using decision trees and real options. We analyzed the derived NPV and B/C and found the best alternative.

We recommend that the methodology used in the case study be used in the decision-making process of weapon system acquisition strategy and project execution. From before the start of the project to the completion of the project, if the real option is used at the time of decision making, it can help the decision maker make a rational choice.

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References

1. Tishler, A.; Dvir, D.; Shenhar, A.; Lipovetsky, S. Identifying critical success factors in defense development projects: A multivariate analysis. *Technol. Forecast. Soc. Chang.* **1996**, *51*, 151–171. [CrossRef]
2. Porter, A.L. *Forecasting and Management of Technology*; Wiley: Hoboken, NJ, USA, 1991.
3. Coates, V.; Farooque, M.; Klavans, R.; Lapid, K.; Linstone, H.A.; Pistorius, C.; Porter, A.L. On the Future of Technological Forecasting. *Technol. Forecast. Soc. Chang.* **2001**, *67*, 1–17. [CrossRef]
4. Daim, T.U.; Kocaoglu, D.F.; Anderson, T.R. Using technological intelligence for strategic decision making in high technology environments. *Technol. Forecast. Soc. Chang.* **2011**, *78*, 197–198. [CrossRef]
5. Robinson, D.K.R.; Huang, L.; Guo, Y.; Porter, A.L. Forecasting Innovation Pathways (FIP) for new and emerging science and technologies. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 267–285. [CrossRef]
6. Cunningham, S.W.; Kwakkel, J. Innovation forecasting: A case study of the management of engineering and technology literature. *Technol. Forecast. Soc. Chang.* **2011**, *78*, 346–357. [CrossRef]
7. Sakata, I.; Sasaki, H.; Akiyama, M.; Sawatani, Y.; Shibata, N.; Kajikawa, Y. Bibliometric analysis of service innovation research: Identifying knowledge domain and global network of knowledge. *Technol. Forecast. Soc. Chang.* **2013**, *80*, 1085–1093. [CrossRef]
8. Jun, S.; Park, S.S.; Jang, D.S. Technology forecasting using matrix map and patent clustering. *Ind. Manag. Data Syst.* **2012**, *112*, 786–807. [CrossRef]
9. Choi, S.; Jun, S. Vacant technology forecasting using new Bayesian patent clustering. *Technol. Anal. Strateg. Manag.* **2014**, *26*, 241–251. [CrossRef]
10. Kim, S.; Jang, D.; Jun, S.; Park, S. A Novel Forecasting Methodology for Sustainable Management of Defense Technology. *Sustainability* **2015**, *7*, 16720–16736. [CrossRef]

11. The Naval Center for Cost Analysis. *Economic Analysis Guide*. 2013. Available online: https://www.ncca.navy.mil/references/DON_Economic_Analysis_Guide.pdf (accessed on 11 June 2018).
12. Baker, H.K.; Dutta, S.; Saadi, S. Management Views on Real Options in Capital Budgeting. *J. Appl. Financ.* **2011**, *21*, 18–29.
13. Trigeorgis, L. A Conceptual Options Framework for Capital Budgeting. *Adv. Futures Options Res.* **1988**, *3*, 145–167.
14. Trigeorgis, L. Real Options and Interactions with Financial Flexibility. *Financ. Manag.* **1993**, *22*, 202–224. [CrossRef]
15. van Putten, I.; MacMillan, A. Making Real Options Really Work. *Harv. Bus. Rev.* **2004**, *82*, 134–142. [PubMed]
16. Mun, J. Real Options Analysis versus Traditional DCF Valuation in Layman's Terms. In *Managing Enterprise Risk: What the Electric Industry Experience Implies for Contemporary Business Elsevier Global Energy Policy and Economics Series*; Elsevier: Amsterdam, The Netherlands, 2006; pp. 75–106.
17. Mun, J. *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decisions*; John Wiley & Sons: Hoboken, NJ, USA, 2002.
18. Katritzky, A.R.; Oliferenko, A.; Lomaka, A.; Karelson, M. Six-membered cyclic ureas as HIV-1 protease inhibitors: A QSAR study based on CODESSA PRO approach. *Bioorg. Med. Chem. Lett.* **2002**, *12*, 3453–3457. [CrossRef]
19. Buurman, J.; Zhang, S.; Babovic, V. Reducing Risk through Real Options in Systems Design: The Case of Architecting a Maritime Domain Protection System. *Risk Anal.* **2009**, *29*, 366–379. [CrossRef] [PubMed]
20. Dixit, A.K.; Pindyck, R.S. *Investment under Uncertainty*; Princeton University Press: Princeton, NJ, USA, 1994.
21. Triantis, A.; Borison, A. Real Options: State of the Practice. *J. Appl. Corp. Financ.* **2001**, *14*, 8–24. [CrossRef]
22. Pennock, M.J.; Rouse, W.B.; Kollar, D.L. Transforming the Acquisition Enterprise: A Framework for Analysis and a Case Study of Ship Acquisition. *Syst. Eng.* **2007**, *10*, 99–117. [CrossRef]
23. Merton, R.C. Lifetime Portfolio Selection under Uncertainty: The Continuous-Time Case. *Rev. Econ. Stat.* **1969**, *51*, 247–257. [CrossRef]
24. Black, F.; Scholes, M. The Pricing of Options and Corporate Liabilities. *J. Political Econ.* **1973**, *81*, 637–654. [CrossRef]
25. Brennan, M.J.; Schwartz, E.S. Evaluating Natural Resource Investments. *J. Bus.* **1985**, *58*, 135–157. [CrossRef]
26. Mcdonald, R.; Siegel, D. The Value of Waiting to Invest. *Q. J. Econ.* **1986**, *101*, 707–727. [CrossRef]
27. Perlitz, M.; Peske, T.; Schrank, R. Real options valuation: The new frontier in R&D project evaluation? *R D Manag.* **1999**, *29*, 255–269.
28. de Weck, O.L.; de Neufville, R.; Chaize, M. Staged Deployment of Communications Satellite Constellations in Low Earth Orbit. *J. Aerosp. Comput. Inf. Commun.* **2004**, *1*, 119–136. [CrossRef]
29. Wang, T. Real Options in Projects and Systems Design Identification of Options and Solution for Path Dependency. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2005; p. 337.
30. Wang, T.; de Neufville, R. Identification of Real Options 'in' Projects. *INCOSE Int. Symp.* **2006**, *16*, 1124–1133. [CrossRef]
31. Engel, A.; Browning, T.R. Designing systems for adaptability by means of architecture options. *Syst. Eng.* **2008**, *11*, 125–146. [CrossRef]
32. Giachetti, R.E. A flexible approach to realize an enterprise architecture. *Procedia Comput. Sci.* **2012**, *8*, 147–152. [CrossRef]
33. Benaroch, M.; Kauffman, R.J. A Case for Using Real Options Pricing Analysis to Evaluate Information Technology Project Investments. *Inf. Syst. Res.* **1999**, *10*, 70–86. [CrossRef]
34. Smith, J.E. Alternative Approaches for Solving Real-Options Problems. *Decis. Anal.* **2005**, *2*, 89–102. [CrossRef]
35. Scott, L.O. Option Pricing when the Variance Changes Randomly: Theory, Estimation, and an Application. *J. Financ. Quant. Anal.* **1987**, *22*, 419–439. [CrossRef]
36. Boyle, P.; Broadie, M.; Glasserman, P. Monte Carlo methods for security pricing. *J. Econ. Dyn. Control* **1997**, *21*, 1267–1321. [CrossRef]
37. Cheah, C.Y.J.; Liu, J. Valuing governmental support in infrastructure projects as real options using Monte Carlo simulation. *Constr. Manag. Econ.* **2006**, *24*, 545–554. [CrossRef]
38. Mun, J. *Modeling Risk: Applying Monte Carlo Simulation, Real Options Analysis, Forecasting, and Optimization Techniques*; John Wiley & Sons: Hoboken, NJ, USA, 2006.

39. Bashiri, A.; Davison, M.; Lawryshyn, Y. Real Option Valuation Using Simulation and Exercise Boundary Fitting—Extended Abstract. In Proceedings of the 22nd Annual International Real Options Conference, Düsseldorf, Germany, 21–23 June 2018.
40. Delaurentis, D.; Davendralingam, N. *Acquisition Management for System-of-Systems: Requirement Evolution and Acquisition Strategy Planning*; Dudley Knox Library: Monterey, CA, USA, 2013.
41. Komoroski, C.; Housel, T.; Mun, J. *A Methodology for Improving the Shipyard Planning Process: Using KVA Analysis, Risk Simulation and Strategic Real Options*; Dudley Knox Library: Monterey, CA, USA, 2006.
42. Pellegrino, R.; Costantino, N.; Tauro, D. Supply Chain Finance: A supply chain-oriented perspective to mitigate commodity risk and pricing volatility. *J. Purch. Supply Manag.* **2018**. [CrossRef]
43. Ranieri, L.; Mossa, G.; Pellegrino, R.; Digiesi, S. Energy Recovery from the Organic Fraction of Municipal Solid Waste: A Real Options-Based Facility Assessment. *Sustainability* **2018**, *10*, 368. [CrossRef]
44. Habib, M.S.; Sarkar, B.; Habib, M.S.; Sarkar, B. An Integrated Location-Allocation Model for Temporary Disaster Debris Management under an Uncertain Environment. *Sustainability* **2017**, *9*, 716. [CrossRef]
45. Brandão, L.E.; Dyer, J.S.; Hahn, W.J. Using Binomial Decision Trees to Solve Real-Option Valuation Problems. *Decis. Anal.* **2005**, *2*, 69–88. [CrossRef]
46. Long, D.; Johnson, S. *The Littoral Combat Ship from Concept to Program Case Studies in National Security Transformation*; Office of the Deputy Assistant Secretary of Defense: Pentagon City, VA, USA, 2007.
47. Adler, J.; Ahart, J.; Housel, T.; Mun, J. *AEGIS Platforms: The Potential Impact of Open Architecture in Sustaining Engineering*; Dudley Knox Library: Monterey, CA, USA, 2007.
48. Angelis, D.I.; Ford, D.; Dillard, J. *Real Options in Military System Acquisition: The Case Study of Technology Development for the Javelin Anti-Tanl Weapon System*; Naval Postgraduate School: Monterey, CA, USA, 2012.
49. Trigeorgis, L. *Real Options: Managerial Flexibility and Strategy in Resource Allocation*; MIT press: Cambridge, MA, USA, 1996.
50. Chang, S.J.F.; Backus, G.R. Applying real options to flexible systems engineering: A proof-of-concept study on capability acquisition of tactical data LINKS. In Proceedings of the 1st Annual 2007 IEEE Systems Conference, Honolulu, HI, USA, 9–12 April 2007; pp. 271–277.
51. South Korea's K2 Tank to run on German Transmission. *Defense News*, 14 February 2018.
52. Lee, P.; Song, G. *Economical Effect of Maneuver Weapon Systems Development*; Korea National Defense University: Seoul, Korea, 2009.
53. Kim, J. *A Research Comparing Domestically Developed Weapon System and Overseas Purchase*; Kookmin University: Seoul, Korea, 2015.
54. Kim, K.; Baek, S.; Baek, Y.; Kim, H.; Park, S. *A Study on Preliminary Feasibility Study Standard Guide of Airport Busuness Field*, 3rd ed.; Korea Development Institute: Sejong, Korea, 2014.
55. Hwang, S. *Methodology of Economic Assessment for Classified R&D Programs*; Science & Technology Policy Institute: Seoul, Korea, 2006.
56. Anderloni, F.; Vangelista, L. *Project Valuation Using Real Options Analysis*; Department of Information Engineering: Hong Kong, China, 2011.
57. Lee, Y. *Application of Real Option Analysis Method in Preliminary Feasibility Study of National R&D Project*; Korea Institute of Science & Technology Evaluation and Planning: Seoul, Korea, 2008.