Coping with Variability in Automotive Product line Architectures Using Real Options

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Abstract

The automotive customers demand new functionality with every new product release and the time-to-market is constantly shortened. The automotive embedded systems are characterized by being mechatronic system which adds complexity. The systems are often resource constrained and trade-offs between the system behavior and the resources required is of great importance. The decisions are usually based on many factors that pull in different directions such as maintenance, portability, usability etc. The complex system and the many uncertain factors create a need for support in the design process. In this paper the use of Real Options is evaluated on a hypothetic but realistic case taken from the automotive industry. The case show how real option valuation provides additional guidance when making system design decisions. Real Options provide the opportunity to analyze the cost of designing for future growth of an platform, based on the estimated value of the future functionality. The value of a flexible design can thereby be quantified making the trade-off between short and long term solution more accurate.

1 Introduction

Today most innovations made within the automotive domain are driven by electronics. According to a 2006 study made by McKinsey [10] they expect the total value of electronics in automobiles to rise from the current 25% to 40% in 2010. The same study mentions that a large Japanese car manufacturer had to recall 160 000 vehicles due to software failure. Another manufacturer recalled 1.3 million cars due to an electrical failure with an estimated cost of EUR 325 million. The automotive customers demand new functionality with every new product release and the time-to-market is constantly shortened. Most design decisions of automotive electronic and electrical (E/E) architectures are done during the early phases. Often, the E/E architecture needs to support a full product line of vehicles or vehicle variants that are released over a number of years. They must allow a large degree of variability to cope with the demands of different customers. To be able to satisfy this growing demand the Original Equipment Manufacturer (OEM) needs to develop architectures that can evolve throughout its lifetime without forcing premature architectural changes.

Similar products in other industries solve this problem by simply adding extra assets to cope with future demands. The cost sensitive automotive industry has to optimize the use of the system limited assets, but in the meantime also be flexible. Figure 1 shows a possible usage of one of the systems limited asset during its lifetime. New functions are consuming the asset and eventually at t5 when a new function is introduced there is a need for an architectural modification. If this is unplanned it would result in a large cost and a delay of market introduction. Because of the rapid increase in functionality that is unfortunately often the case.

The design decisions are usually based on many factors that pull in different directions such as maintenance, portability, usability etc. The complex system and the many uncertain factors create a need to define methods which can provide guidance in the design process. This paper aims to evaluate if the use of Real Options could be a suitable method to value flexibility and thereby improve the quality of design decisions. Our main contribution is to show how Real Options can be used to value the possible system designs in an product line architecture and thereby improving the decisions.

1.1 Paper outline

The evolution of financial options into Real Options are discussed in Section 2, where also the social and organizational aspect of using Real Options are briefly discussed.

Three different methods of valuing Real Options are studied in Section 3. The question if Real Options are suitable to value the flexibility in embedded system design is answered in Section 4. In Section 5 a hypothetic but realistic case from the automotive industry is analyzed using Real Options. Various related work is presented in Section 6. In the last section conclusions are made and future work presented.

2 Introducing real options

2.1 Definition

Using options theory is one approach to deal with the high level of uncertainty when making design decisions in the early phases. The theory derives from finance where an option is the right but not the obligation to exercise a feature of a contract at a future date [11]. An option has a value because it gives its owner the possibility to decide in the future whether or not to pay the strike price for an asset whose future value is not known today. An option provides therefore a right to make the costly decision after receiving more information. There are two different types of options, American and European. A European option may only be exercised at maturity opposite to an American option that can be exercised any time until the exercise date. Real Options could be seen as an extension of financial option theory to options on real (nonfinancial) assets [1]. Copeland [7] defines a real option as: ”the right, but not the obligation, to take an action (e.g. deferring, expanding, contracting, or abandoning) at a predetermined cost called the exercise price, for a predetermined period of time - the life of the option.”

2.2 Real options today

Since the 1990s options theory has started to be utilized within the field of engineering. It is then called Real Options and was developed to manage the risk of uncertain

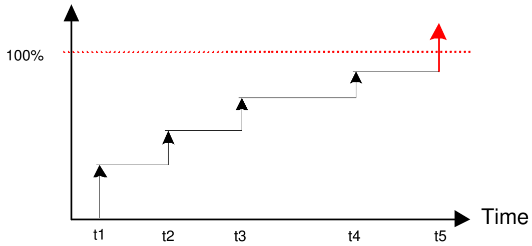

Figure 1. New functions are consuming the systems limited asset.

design decisions. In 2002 de Neufville [9] coined the expressions Real Options in and on projects. Real Options on projects treats the enabling technology as a black box while Real Options in projects are options created by changing the actual design of the technical system. Real Options on projects provide a more accurate value of the project and Real Options in projects support the decision on what amount of flexibility to add. ”Real Options on projects are mostly concerned with an accurate value to assist sound investment decisions, while Real Options in projects are mostly concerned with go or no go decisions and an exact value is less important.” [16]

2.3 Social considerations

Real Options do not only provide a way of valuing system designs, but it also forces the developer to think about the future in a systematic manor. By giving future flexibility a value it assists the developing organization in making decisions and also enables a way of predicting the growth of the complete system [3]. Leslie concludes the article ”The real power of Real Options” with ”The final, and perhaps greatest, benefit of real-option thinking is precisely that - thinking” [14]. The possibility of changing the way people think might also be the hardest part in bringing acceptance to new methods such as using Real Options. The new method must not only be better than the one it is replacing, it should also be triable, observable and have low complexity [7].

3 Valuing real options

One of the advantages with Real Options compared to many other architecture evaluation methods is the possibility to value different system designs and thereby finding the most economically sound investment. This is probably the most complicated part of using Real Options, and during the years since ”Real Options” was coined there have been several approaches to calculate its value. They all have various assumptions and we will in this section evaluate the most appropriate for our case. There are three general solution methods [1]:

- **Black-Scholes-Merton model.** The partial differential equation approach calculates the option value by solving a partial differential equation including the value of a replicating portfolio.
- **Binomial model.** The dynamic programming approach lays out the possible future outcomes and folds back the value of optimal future strategy.
- **Monte Carlo simulation.** The simulation approach averages the value of the optimal strategy at the

decision date for thousands of possible outcomes.

We will now present the the first two models in more detail, whereas the third model is beyond the scope of this study.

3.1 Black-Scholes-Merton model

The Black-Scholes model for which they later received the Nobel-price was created by Black and Scholes 1973 and is widely used on financial options. The Black-Scholes model makes two major assumptions that concern our case; it demands a replicating portfolio and only supports European type options. A replicating portfolio contains assets with a value matching those of the target asset. The replicating portfolio of financial options can easily be found on the stock exchange as the stock value, but when looking at Real Options that are not traded it can be very difficult to find. Considering our case it seems very unlikely that assets needed is exercised at a predefined time. Sullivan [15] discusses the assumptions made and argues *"They will not hold for some, perhaps many, software design decisions.*" More recently Copeland [8] argues *"There are valuation methodologies that effectively capture the complexities and the iterative nature of managerial decisions, and the Black-Scholes-Merton model is not the only, or even the most appropriate, way to value Real Options.*" Also Amram who provides [1] a four step solution using Black-Scholes states *"The Black-Scholes solution is appropriate for fewer Real Options applications, but when appropriate it provides a simple solution and a quick answer.*" The conclusion is that the Black-Scholes model is suitable for financial options, but hard to use in our case.

3.2 Binomial model

The binomial model does not need a replicating portfolio [5] and also supports American type options. The initial value, *A*, changes with each time interval and either goes up with the probability *p* to A_u or down to A_d until its final date [1]. The value of the asset (*A*) at each decision point is given through Equation (1) with *r* being the riskfree interest rate and σ the volatility and the time period Δt.

$$A = (pA_u + (1-p)A_d)e^{-r\Delta t} \quad (1)$$

Assuming that the underlying asset has an symmetric up and down movement *(u=1/d)*:

$$u = e^{\sigma\sqrt{\Delta t}} \quad (2)$$

$$d = e^{-\sigma\sqrt{\Delta t}} \quad (3)$$

$$p = \frac{e^{r\Delta t} - d}{u - d} \quad (4)$$

Looking back at our case the value of the flexibility option would change during the development stages. This approach will be future developed in Section 5

4 Real options in embedded system design

There are as many Real Options in embedded system design projects as in any other engineering project. Those systems contains a large amount of design variables and parameters that can be valued as Real Options in projects.

4.1 Automotive embedded systems

The building blocks of an automotive E/E system consists of electrical control units (ECU) connected to communication networks. The communication networks are usually divided into subnetworks and the communication between those are made through gateway ECUs connected to a backbone. Different sensors and actuators are connected to the ECUs depending on the function allocated to the ECU.

4.2 Suitability of real options

To find out if Real Options would be a support in embedded system design one needs to clarify the characteristics of this domain. As stated earlier [10] the large volume and cost of the product makes errors in the design very expensive. Also conflicting requirements found late in the development phase cause a high cost. At the same time there is a very high level of uncertainty during this design phase and important decisions are made by a small group of engineers [2]. The automotive embedded systems are characterized by being mechatronic system which adds complexity. The systems are often resource constrained and trade-offs between the system behavior and the resources required is of great importance [13].

When to use Real Options is explained by many authors. Copeland [7] states *"It is making the tough decisions - those where the Net Present Value is close to zero - that the additional value of flexibility makes a big difference.*" This is in our case true when developing a new functionality where the market demand is very uncertain. If the design would include a real option to abandon or change course the risk taken could be minimized. Under these condition, the difference between real option valuation and other decision tools is substantial.

4.3 Real options in embedded systems

There are many new functions that are about to be introduced or already introduced that have a large impact on the electrical system of automotive vehicles. It would not be wise to analyze all the real options available. When designing a function distributed over a communication network there are some assets that are generic and can easily be used by other functions. Such Real Options could be bus-capacity, available I/O, CPU-capacity, memory space or even energy. When available they provide an increased amount of flexibility or available design space and thereby added value. Other assets used in the function such as application software, cable harness, sensors or actuators are often very dedicated to the specific function. When designing a distributed function one would early need to secure the common resources, but the dedicated assets can be decided upon later. Those assets do not provide flexibility to the whole system, but they can be seen as the exercise price of the real option providing flexibility to the function.

Many design features such as memory and processor capacity can be seen as options, i.e. giving you the right but not the obligation to use them in the future. Component based design can also be seen as an option, where the initial investment is the additional cost of making the design of the system component based. The added value to the system is mainly the possibility of the component to be reused, but also a shortened time-to-market and the value of a flexible design. Current and future technical demands of the system together with economical and organizational demands call for a systematic evaluation method. Using Real Options as a method to evaluate alternative solutions enables the possibility to value the flexibility of the technical solution. A solution that is more likely to withstand change due to future demands has therefore a higher value when evaluated using real options compared to traditional evaluation methods. To enable the possibilities of future reuse the system needs to be designed with interfaces between components (both SW and HW) that are prepared for future needs. During the development process multiple design steps will be made through design decisions, each decision will narrow down the available design space. The design space is the amount of possible solutions that can be chosen and is therefore also tightly coupled with the requirements.

The design will be different depending on how long the system is planned to withstand future change. To evaluate what level of flexibility is appropriate one must therefore first provide the rough requirements of future needs. Given the estimated value of the future functionality a real option analysis will then show what amount of flexibility should be added to make the investment adequate.

5 Example: Lane departure warning

To analyze the method and its usefulness a hypothetical but realistic example is made taken from the automotive industry.

5.1 System overview

A lane departure warning function warns the driver if the vehicle unintentionally alters its course outside the lane. When developing a function such as lane departure warning one has to take into consideration what future demands will be assigned to the system design. A basic standalone lane departure system would include a lane recognition module and a driver alert module. By adding information such as steering wheel angle and vehicle speed taken from the vehicle network the quality of the driver alert could be improved. A first improvement could therefore be integration with the vehicle network. Future improvement of the driver alert quality could for instance involve smoothness analysis of the vehicle position inside the lane. There are also future functions and enhancement of existing functions that could be implemented using the capabilities of the system. Examples could be analysis of driver distraction, driver quality, active steering, object classification (road signs) or automated vehicle control. The user interface could also be varied or combined by optical, acoustic and haptic warning.

5.2 Real option problem

Given the future requirement of the lane departure system a design can be made (Figure 2) for a system that can support all future requirement. From this design concept the quantitative data needed to perform an real option valuation need to be extracted (Figure 3). How to estimate and retrieve this data is out of the scope of this paper, but a challenge for future research.

The planned lifetime of the platform is 3 years, and if the function has not been implemented before the expiration date the value of the real option is lost. The minimum goal of the investment in the new platform is to exceed the interest gained from the companys risk free interest rate set to 3%. The cost of preparing the platform for future expansion in terms of additional product cost (memory, network connection, etc.) and development time is equal to the price of the real option and estimated to $0.5 million. The exercise price $1.5 million of finally implementing the function includes the cost of sensors, cables, developing application

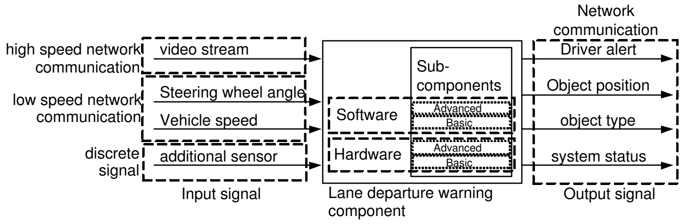

Figure 2. Advanced lane departure system

Option on stock	Real option in embedded systems
Option value (V)	The value of designing flexibility
Option price (C)	Cost of designing for flexibility
Exercise price (X)	Cost of utilizing flexibility
Underlying asset value (S)	Current value of implementing flexibility
Volatility (s)	Uncertainty of costumer demand
Time to exercise (t)	Time when the option is exercised
Time to expiration (T)	Lifetime of the current system

Figure 3. Factors affecting the value of an option.

software and sales and marketing activities. The expected value of the future function which represents the underlying asset is given through a simplified model (5) to be $2 million. The product cost is the estimated costs during the system lifecycle. The volatility of the investment, mainly due to the uncertainty of future demand is predicted to 25%.

$$A = expectedvolume * (custumerprice - productcost) \tag{5}$$

5.3 Real option valuation

A system could be designed to suit the different future needs and by using the binomial model the value of the Real Options can be calculated using the method shown in Section 3.2. The price of the real option was $0.5 million and the current value is calculated to $ 0.71 million, which means that adding the cost of flexibility is a good investment. The results show that the future option value increases with the number of requirements implemented (Figure 4). If only a low number of requirements will be demanded the value of the option will be lost. It also shows how the risk changes with the probability. This risk could be eliminated by not implementing the possibility to support a certain requirement. This would lead to a limited design space where an improved functionality cannot be implemented without a re-design of the system. Finally the figure illustrates how the binomial model fits the development process and as Amram states gives the user a *"peek under the hood"* [1].

5.4 Discussion

The results show that investing in a flexible platform would most likely be a sound investment if a large part of the future requirements were implemented during the system life cycle. The diversity of the proposed functionality makes it very uncertain what functionality will be implemented, which also is the reason why flexibility has a value. The prediction of the volatility and the value of the underlying asset is crucial to the results. One of the strengths

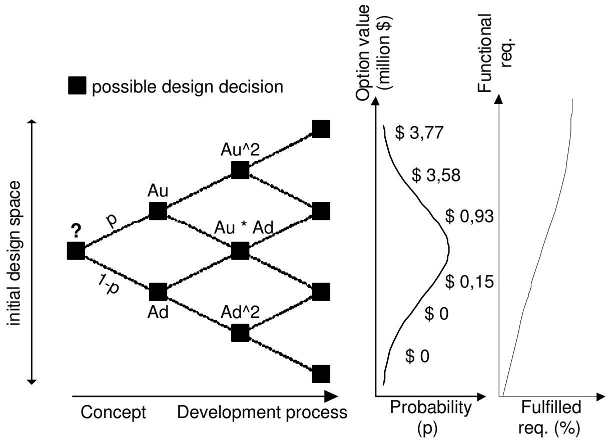

Figure 4. The decisions made narrows the initial design space.

when using real option valuation is that the uncertainty is taken into account and not left out of the calculation. It also provides a valuation method that can be used to analyze different future scenarios. Similar analysis can be done to estimate the value of future functions by iteration of sales volumes, customer price, etc.

6 Related work

Real Options is far from being the only method developed for valuing architectures. There are few methods that makes an economic consideration, CBAM [12] being an exception. Real Options is unique by also considering the flexibility and the architectural evolution over time [4]. Our literature survey has found three research contributions [6][3][5] that involve the usage of real options in system design involving software or hardware. None of them addresses embedded systems or the automotive domain explicitly.

Browning et al. [6] extends Real Options "in" projects to *architecture options* and presents a theoretical example where stakeholder overall value increases with 15% by designing the system for the right amount of adaptability. The framework presented shows a way to implement the optimal degree of flexibility. The initial research propose using the model of Black and Scholes to calculate the value of the Real Options, but do not present a case. Browning shows that architecture options provides the information to better predict the need for system upgrades and thereby increases the lifetime value of the system.

Bahsoon et al. [3] uses the concept of *ArchOptions* to value the stability and scalability [3] of software architectures. ArchOptions are valued using the model of Black and Scholes and a replicating portfolio is therefore needed. The portfolio is valued by the requirements it supports during the operation of the software system.

Banerjee [5] argues the need for flexibility and presents the solution of flexibility options compared to a fixed design. The value of the flexibility option is calculated using the binomial model that does not need an replicating portfolio and also supports American type options. The work done by Banerjee seems to be what best meet our prior stated problem definition.

7 Conclusion & Future work

Real Options theory is a very powerful tool that enables analysis of both economic and engineering factors. It presents a possibility to put an economic value of system adaptability and could therefore support the design decisions in the early phases. Real Options provide the opportunity to analyze the cost of designing for future growth of an platform, based on the estimated value of the future functionality.

When developing an embedded system using Real Options each function would first buy the right but not the obligation to use the asset at a future date. The real option approach could when fully developed provide not only evaluation but also prediction of future needs.

Real Options on system design is a newly added extension of the option theory and there is not a developed method available. There is research needed to find ways on how to calculate volatility and value of the initial asset. There is also a need to make case studies focusing on the acceptance of the result in the developing organization.

References

[1] M. Amram and N. Kulatilaka. *Real options*. Harvard Business School Press Boston, Mass, 1999.

[2] J. Axelsson. Cost models with explicit uncertainties for electronic architecture trade-off and risk analysis. Orlando, USA, 2006. 16th Annual International Symposium Proceedings, INCOSE 2006.

[3] R. Bahsoon and W. Emmerich. Archoptions- a real options-based model for predicting the stability of software architectures. In *Proceedings of the ICSE Fifth Workshop on Economics-Driven Software Engineering Research*, pages 38–43, 2003.

[4] R. Bahsoon and W. Emmerich. Evaluating software architectures- development, stability, and evolution. In *Proc. of IEEE/ACS Computer Systems and Applications*, pages 47–57, 2003.

[5] P. Banerjee. *Describing, assessing and embedding flexibility in system architectures with application to wireless terrestrial networks and handset processors*. Master Thesis, Massachusetts Institute of Technology, System Design and Management Program, June 2004.

[6] T. R. Browning and A. Engel. Designing systems for adaptability by means of architecture options. Orlando, USA, 2006. 16th Annual International Symposium Proceedings, INCOSE 2006.

[7] T. Copeland and V. Antikarov. *Real Options: A Practitioner's Guide*. Texere, New York, NY., 2001.

[8] T. Copeland and P. Tufano. A real-world way to manage real options. *Harvard business review*, 82(3):90–99, 2004.

[9] R. de Neufville. Real Options: Dealing With Uncertainty in Systems Planning and Design. *Integrated Assessment-An International Journal*, 4(1):26–34, 2003.

[10] D. Hoch, W. Huhn, U. Naher, and A. Zielke. *The race to master automotive embedded systems development*. McKinsey Company, Automotive and assembly sector business technology office, Germany, 2006.

[11] J. C. Hull. *Options, Futures, and other derivative securities 2nd edition*. Prentice Hall International Editions, New Jersey, USA, 1993.

[12] R. Kazman, J. Asundi, and M. Klein. *Making Architecture Design Decisions: An Economic Approach*. Number 2002-TR-035. Carnegie Mellon Software Engineering Institute, September 2002.

[13] O. Larses. *Architecting and modeling automotive embedded systems*. PhD thesis, Royal Institute of Technology, Stockholm, Sweden, 2005.

[14] K. Leslie and M. Michaels. The real power of real options. *The McKinsey Quarterly*, 3, 1997.

[15] K. J. Sullivan, P. Chalasani, S. Jha, and V. Sazawal. Software design as an investment activity: A real options perspective. *Real Options and Business Strategy: Applications to Decision Making*, pages 215–262, 1999.

[16] T. Wang. *Real Options in Projects and Systems Design - Identification of Options and Solution for Path Dependency*. PhD thesis, Massachusetts Institute of Technology, Cambridge, MA, 2005.