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Using Real Options in Embedded Automotive System Design

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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 systems which adds complexity. The systems are often resource constrained and trade-offs between the system behaviour and the resources required is of great importance. The system complexity and the many uncertain factors create a need for support in the design process. 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. The valuation method using Real Options provides the opportunity to analyze the cost of designing for future growth of a platform, based on the estimated value of the future functionality.

In this paper the use of Real Options is applied on a real case within the automotive industry. The studied company develops commercial vehicles for a broad range of applications. In this case study a valuation is performed on two different design alternatives of function allocation. The design alternatives vary in hardware, software, cabling etc. The case study has been performed together with the developing organization and it has therefore been possible to observe the acceptance of the method. The study shows how Real Option valuation provides valuable guidance when making system design decisions and more importantly also show how it can be used and accepted by system engineers. The method does not only provide a way of valuing system designs, but it also forces the system engineer to think about the future in a systematic manor. The value of a flexible design can thereby be quantified making the trade-off between short and long term solutions more accurate.

Introduction

Today most innovations made within the automotive domain are driven by electronics. According to a 2006 study made by McKinsey [Hoch et. al 2006] they expect the total value of electronics in automobiles to rise from the current 25% to 40% in 2010. 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's limited assets, but in the meantime also be flexible. The design decisions are usually based on many factors that pull in different directions such as maintenance, portability, usability etc. The complexity of the 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 the use of Real Options as a method to value flexibility and thereby improve the quality of design decisions. Our main contribution is to show a real case how Real Options can be used to value the possible system designs and thereby improving the decisions.

Paper outline

In the first section the evolution of financial options into Real Options is discussed and briefly also the social and organizational aspect of using Real Option. Three different methods of valuing Real Options are then studied. The question if Real Options are suitable to value the flexibility in embedded system design is answered in section “Real options in embedded system design. A case study on network usage from the automotive industry is then analyzed using Real Options. Various related work is then presented and followed by conclusions and future work.

Introducing real options

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 [Hull 1993]. 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 therefore provides 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 [Amram et al. 1999]. Copeland [Copeland et al. 2001] 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. ”

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 design decisions. In 2001 de Neufville 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.” [Wang 2005]

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 [Leslie et al. 1997]. 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” [Leslie et al. 1997]. 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 [Copeland et al. 200].

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 calculating 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 [Amram et al. 1999]:

- *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 first two models in more detail, whereas the third model is beyond the scope of this study.

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 [Sullivan et al. 1999] discusses the assumptions made and argues ”They will not hold for some, perhaps many, software design decisions.” More recently Copeland [Copeland et al. 2001] 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 [Amram et al. 1999] 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.

Binomial model

The binomial model does not need a replicating portfolio [Banerjee 2004] and also supports American type options. The initial value, A, changes with each time interval and either goes up with the probability p to Au or down to Ad until its final date [Amram et al. 1999]. The value of the asset (A) at each decision point is given through Equation (1) with r being the risk free interest rate and σ the volatility and the time period Δt.

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

Assuming that the underlying asset has an symmetric up and down movement $u = \frac{1}{d}$

$$u = e^{\sigma\sqrt{\Delta t}} \; (2) \qquad d = e^{-\sigma\sqrt{\Delta t}} \; (3) \qquad p = \frac{e^{r\Delta t} - d}{u - d} \; (4)$$

Looking back at our case the value of the flexibility option would change during the development stages.

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 contain a large amount of design variables and parameters that can be valued as Real Options in projects.

Automotive embedded systems

The building blocks of an automotive E/E system consist 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.

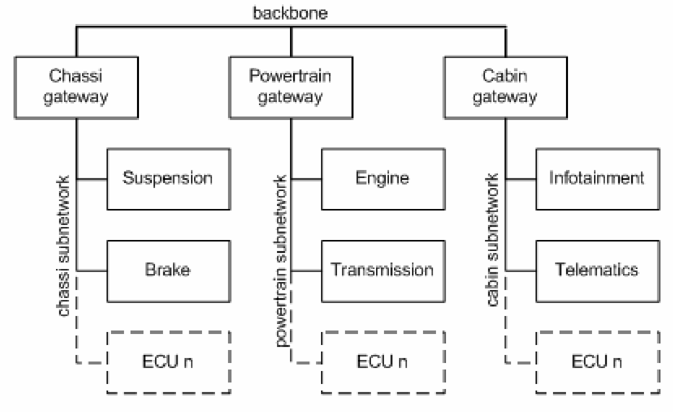

Figure 1 A typical vehicle communication network

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 [Hoch et al. 2006] the large volume and cost of the product makes errors in the design very expensive. Also conflicting requirements found late in the development phase causes 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 [Axelsson 2006]. 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 behaviour and the resources required is of great importance [Larses 2005]. When to use Real Options is explained by many authors. Copeland [Copeland et al. 2001] 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 conditions, the difference between real option valuation and other decision tools is substantial.

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. 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. 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.

Case study: Network usage

To analyze the method and its usefulness it is applied on a real case taken from the automotive industry.

System overview

Network communication is a limited resource within the automotive industry. Each network has a predefined maximum capacity and the utilisation is also dependent on the physical location of the network cable. There is a growing market demand to monitor and control different vehicle functions through the use of external devices. To meet this requirement one must provide a way to connect external communication devices to the vehicle. A pre-study has found two alternative ways to provide this feature (Figure 2). Design alternative 1 provides this feature by connecting the communication link directly to the current cabin gateway ECU through an existing but unused bus interface, and the advantage is a low development cost. Alternative 2 uses a new ECU to create the external communication. Alternative 2 is more expensive in development cost and component cost, but does not use the last available communication link in the cabin gateway. The communication link is a limited resource which can be of interest to a large number of functionalities, but those functionalities cannot be safely mixed with an external device. Alternative 2 thus gives a higher flexibility for future functionality than Alternative 1.

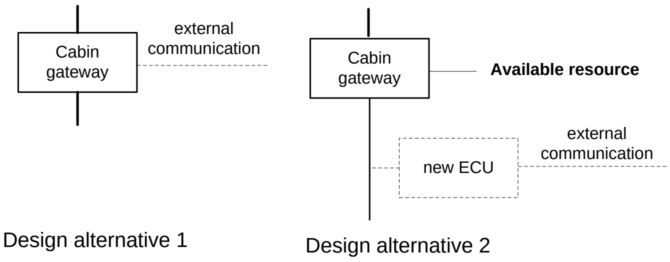

Figure 2 Two design alternatives to provide the demanded feature.

Traditional valuation

The traditional method to calculate the value of an investment is by calculating its Net Present Value (NPV). The development cost of alternative 1 is zero and SEK 5 million (Swedish krona) for alternative 2. The cash flow of alternative 1 is higher due to its low component cost. The difference in NPV between the two alternatives is SEK 6.8 million given the annual discount rate of 11%. The analysis of the valuation tells us to choose alternative 1, but this does not take the value of flexibility into account.

		Cashflow					
	Development cost	1st year	2nd year	3rd year	4th year	5th year	**NPV**
Alternative 1	0	15,5	15,5	15,5	15,5	15,5	57,3
Alternative 2	-5	15	15	15	15	15	50,4

Difference 6,8

Table 1 The calculated NPV of the two design alternatives in SEK.

Real option problem

The communication link provides flexibility to the system and its value can be calculated using real option valuation. The product portfolio gives us a set of functionalities which could require the use of the communication link. From those design concepts the quantitative data needed to perform a real option valuation need to be extracted (Table 2).

Option on stock	Real option in embedded systems
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 (σ)	Uncertainty of costumer demand
Time to expiration (T)	Lifetime of the current system
Option value (V)	The value of designing flexibility

Table 2 Factors affecting the value of an option.

The data needed is provided through the internal pre-study. The planned lifetime of the platform is 5 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 alternative is to exceed the interest gained from the companies risk free interest rate (5%). The exercise price SEK 2.9 million of finally implementing the function is an average of the potential functions found in the product portfolio. The exercise price includes the cost of ECU, sensors, cables, developing application software. The expected value of the future function which represents the underlying asset (S) is given through a simplified model (5) to be SEK 10 million. The product cost is the estimated costs during the system lifecycle. The volatility is a measure of the annual up or down movement of the option value. It is predicted to be 25% mainly due to the uncertainty of future demands.

S = expected volume x (customer price - product cost) (5)

Real option valuation

Real option theory provides an extension to the traditional NPV valuation by adding the value of flexibility. This so called expanded NPV is the sum of the static NPV and the value of the option premium [Trigeorgis 1988]:

Expanded NPV = Static NPV + Option premium (6)

Alternative 2 would be a sound investment if the value of the option premium is higher than the calculated difference (SEK 6.8 million) in Table 1. By using the binomial model the value of the option premium can be calculated. The current value of the option is calculated to SEK 7.7 million, which means that adding the flexibility is a good investment compared to the alternative without flexibility.

The results show that the future option value increases with the number of requirements implemented (Figure 3). 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 redesign 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” [Amram et al. 1999].

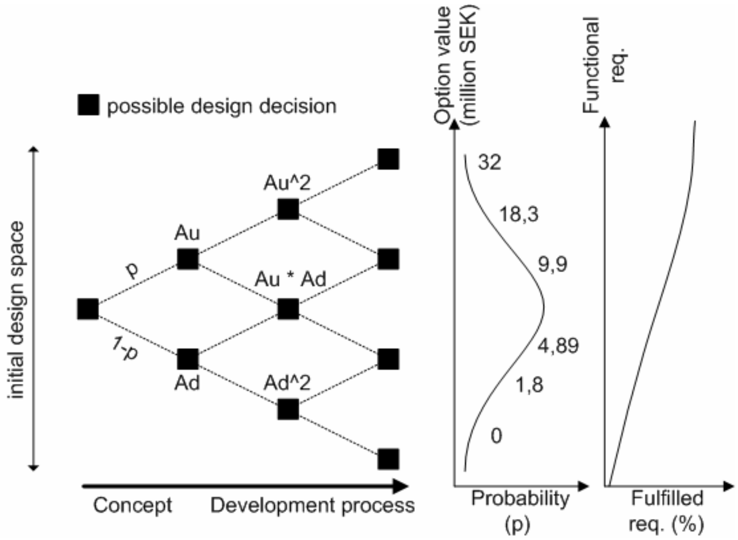

Figure 3 The future option value increases with the number of requirements implemented.

Discussion

The results show that investing in a flexible design 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 are crucial to the results. One of the strengths 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.

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 [Kazman et al. 2005] being an exception. Real Options is unique by also considering the flexibility and the architectural evolution over time [Bahsoon et al. 2003a]. Our literature survey has found three research contributions [Browning et al. 2006] [Bahsoon et al. 2003b] [Banerjee 2004] 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. 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 proposes 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. uses the concept of ArchOptions to value the stability and scalability 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 [Banerjee 2004] 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 a replicating portfolio and also supports American type options. The work done by Banerjee seems to be what best meet our prior stated problem definition.

Conclusion & Future work

This paper has shown that 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 a 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. There is also a need to make case studies focusing on the acceptance of the result in the developing organization.

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Biography

Håkan Gustavsson is an industrial Ph.D student at Mälardalen University in Västerås. Håkan has been working with vehicle electronic systems integration and architecture since 2002 at Scania CV AB in Södertälje. He is currently employed as an Industrial Ph.D. student within the electrical systems predevelopment department at Scania. He received his B.Sc. in Electrical Engineering at the Royal Institute of Technology 2002 after completing his studies with a final year at Fachhochschule Zentral Schweiz. His research area is systems engineering of vehicle electronics. Studying methods to analyze and improve the decisions made during the early phases of E/E-system development.

Jakob Axelsson received an M.Sc. from Linköping University in 1993, and a Ph.D. in 1997 for a thesis on hardware/software codesign of real-time systems. He has been working at ABB Corporate Research and ABB Power Generation (now Alstom) in Baden, Switzerland, Volvo Technological Development (now Volvo Technology) and Carlstedt Research & Technology in Göteborg, Sweden. He is currently with the Volvo Car Corporation in Göteborg, where he is program manager for research and advanced engineering for electrical and electronic systems. He is also an adjunct professor in software and systems engineering at Mälardalen University in Västerås.

Jakob Axelssons research is mainly in the area of complex technical systems, with focus on methods and tools to handle the early phases of product development. In particular, embedded systems and automotive applications are studied, but other products are also of interest.