Flexibility Strategy – Valuing Flexible Product Options

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Abstract

Flexibility is very critical in addressing changing customer needs in the highly competitive market scenario that we see around us nowadays. Flexibility can be understood as the innate ability of a system or product to support new functions and to perform these at some finite range of operating conditions and capacity levels during later stages of its lifecycle. Usually the range of expected behavior is fixed in a specification. This paper evaluates the conditions where a flexible architecture is no longer financially viable vis-à-vis fixed architectures. This paper will contribute to research in Systems Engineering by demonstrating how alternative valuation methods can yield an estimate of product option value, yielding information on the relative value of flexibility options during product design. The application of the flexible product option valuation framework is described using a case of a handset processor in a 2G/3G wireless network context. Black-Scholes model and the Binomial model are presented as methods for computing the economics of financial options.

Introduction

There is a general recognition that flexibility is a desirable quality if there is bounded uncertainty in the future usage of the system. These uncertainties can be due to dynamic customer needs, technology, corporate strategy, market conditions, competitive scenario, economic and regulatory policies among other factors. Due to this, a key interest in industry today is to embed flexibility in Product and System Architecture. In order to embark on a research initiative on flexibility, we need to substantiate the dimension and attributes of flexibility and establish the methods by which flexibility can be described in a rigorous but generic fashion. Flexibility can be understood as the innate ability of a system or product to support new functions and to perform these at some finite range of operating conditions and capacity levels during later stages of its lifecycle. Usually the range of expected behavior is fixed in a specification. One of the definitions of Flexibility in the published literature is *the property of a system that allows it to respond to changes in its initial objectives and requirements –both in terms of capabilities and attributes- occurring after the system has been fielded* [1].This differs from robustness, where a fixed behavior is specified for an uncertain range of external influences onto the system. It also differs from agility, which is the ability of a system to be modified or adapt itself to wholly unanticipated operating conditions or functional requirements as shown in Figure 1 : Flexible Design Objective Space (Adapted from [1])).

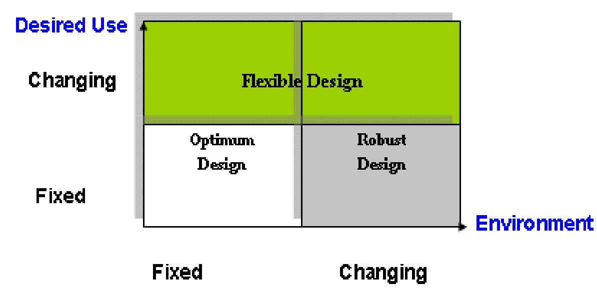

Figure 1 : Flexible Design Objective Space (Adapted from [1]))

Describing Flexibility

Functional, Capacity and Performance flexibility dimensions are the "results" of a flexible product. These dimensions can be achieved by Reconfigurability, Platforming and Extensibility [2]. We used Crawley's architectural framework [3] to derive these three categories of favorable product "features". Almost all products, transform one or many beneficial attributes. The Transformation process defines the first category of flexibility dimension. The Transformation process acts on a set of attributes. We can also see them as inputs to the transformation function. Crawley [4] explains that goods and services deliver value to beneficiaries, primarily by acting on one or more operands [4].

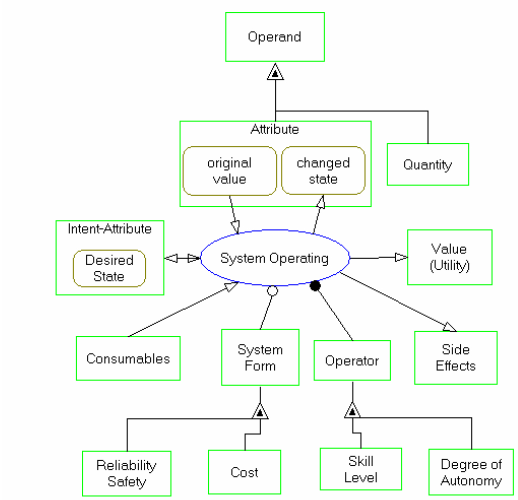

Figure 2 Generic Object-Process-Diagram of System Operating. Source [3]

The operand in matter transportation systems are passengers and cargo. In information transfer systems – such as wireless networks - the operands can be real time voice signals, alphanumeric messages, data files or multimedia data streams. The information transfer process is described by communications theory. An object-process description for generic systems has been developed by Crawley, see
Figure 2 Generic Object-Process-Diagram of System Operating. We can refer to this generic view to develop a more specific view of the dimensions of flexibility. Functional flexibility can be expressed as the ability to either effect different types of processes on the same operand, or to effect the same process on different types of operands, see Figure 3 OPD Representation of Flexibility: Functional flexibility.

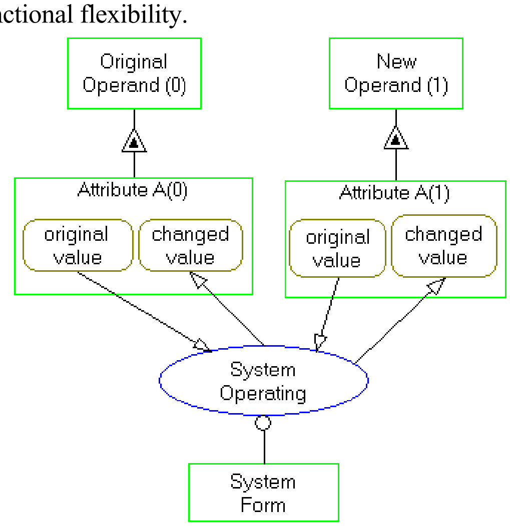

Figure 3 OPD Representation of Flexibility: Functional flexibility

The notion of performance can be understood as the difference between the changed state and the desired state, capacity is related to the quantity (amount of) operand see Figure 4 OPD Representation of Flexibility: Capacity and Performance Flexibility. These dimensions would be defined by the range of the Performance and the Capacity related attributes which are part of the transforming attribute of the primary intent and the operating attribute of the process. There is another class of attributes which are "Resource Attributes" (e.g. Cost), which would set the constraints for the architectural tradeoff and cost/benefit analysis.

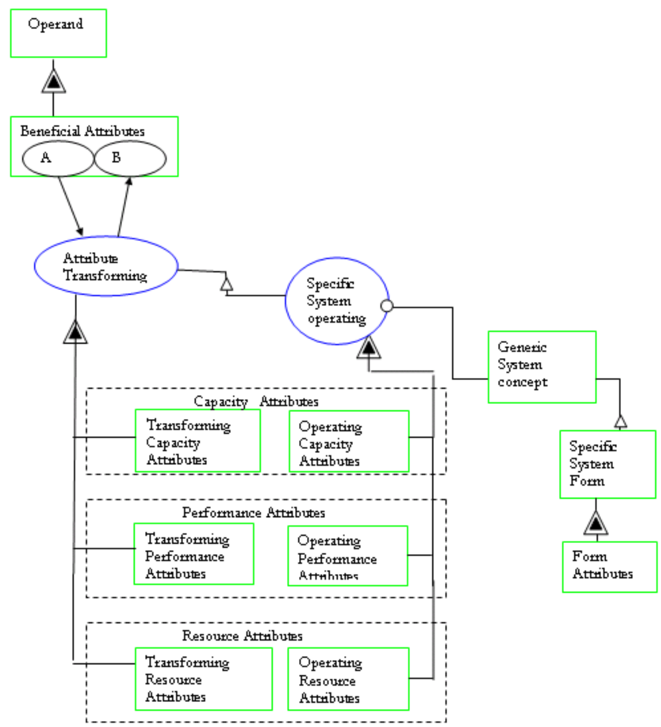

Figure 4 OPD Representation of Flexibility: Capacity and Performance Flexibility

Functional, Capacity and Performance flexibility dimensions are the "results" of a flexible product. These dimensions can be achieved by Reconfigurability, Platforming and Extensibility [2] wherein Product flexibility is be achieved by activating dormant features or adding to existing features to provide enhanced functionality at a later part of product life cycle.

Examples of Flexibility

Hardware (Processors).

A processor design optimized for only a particular class of application, leads to the constraint of meeting needs of only one market segment. There is an uncertainty associated with how the application scenario, will evolve.

Implementing design features for a flexible feature (e.g. cache architecture), we incur a cost in terms of additional design effort, complexity and allocation of resources, which detract from traditional performance metrics (for example it may lead to higher power and die cost). By implementing flexible design features which enable customization of applications, by enabling of an additional on-chip cache at a later decision point in time we can potentially maximize the net benefit by meeting new market needs which may translate into a higher ASP (average selling price) for each unit when the new features are enabled. These features can be:

- Operating Power Supply range changed to support mobile/desktop functionality.
- Multi-Threading enabled for greater CPU performance.
- Security features enabled in wireless handsets for premium market segments.
- Additional cache enabled for better performance.

Software (Network Applications).
A distributed network application can be designed, keeping in mind the functional, capacity and performance scalability. Such an application could have "hooks" to add a feature, or increase the application capacity at a later point in time. These features can be

- Capacity of the database increased to meet increased capacity needs
- Additional servers, with different instances of the application running in a load sharing mode to increase the performance of the network application.
- Additional application features enabled (either on the same server or on different server).

The software "flexibility" features can be designed and embedded in a product and activated later based on license agreements (increased capacity or functionality). Configurability, which is particularly important from the point of view of software products, can be is perceived as a feature in a product to enable the flexibility dimensions in the future.

Civil Architecture.
The concept of extensibility, as defined by Crawley [3] was to enable a system to be scaled up significantly in the future or "organically integrate with a larger systems". For this, he believes that there should be a "master plan" to have a future map of this extensibility and the interfaces must be designed with this in mind. Provision for expansion slots for an additional bedroom or a new barn under the master plan of a house could be example of this extensibility.
From the context of the dimensions of flexibility, the provision to add an additional bedroom provides a capacity flexibility and provision to add a new barn provides a functional flexibility.

Transportation
Blended Body Wing architecture presents an excellent example of modular platform architecture, which enables flexibility [4]. The use of a single flexible platform enables Boeing to be able to design a system which can be adapted to meet the demands of the market. Boeing invests large amounts of R&D capital investment, in face of uncertainty (it can not predict accurately the demand for either type of aircraft - Commercial, Cargo, and Military).

Flexibility Attributes

Architecture Trade Methodology can be used to map the Design space to the Objective space using a system model, to evaluate different architectures [5]. The Flexibility objective space can be mapped to a subset of this Objective Space, which would necessitate incorporation of a range of design space in the overall flexible architecture. The identification of the flexibility objective space will depend on factors that would address uncertainties due to dynamic customer needs, technology, corporate strategy, market conditions, competitive scenario, economic and regulatory policies among other factors. An example of this space is shown in Figure 5 Flexibility Design and Objective Space. Adapted from [6].

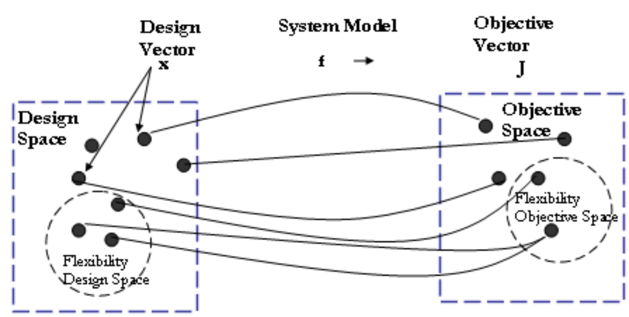

Figure 5 Flexibility Design and Objective Space. Adapted from [6].

Each one of the three dimensions of flexibility: Functionality, Performance, and Capacity, consists of many attributes, which can also be thought of as requirements. These requirements would define the form related design attributes and map into a part of the overall objective space, by defining the flexible objective space. However, we reserve the word "requirements" for concrete mandatory needs required for the delivery of the system, while these attributes are based on a prediction of what the system might morph into in the future. The attributes of the three dimensions are therefore:

Functional attributes:
$\mathbf{Fa = [Fa_1, Fa_2, \ldots, Fa_l]}$

Where l is the number of Functional attributes.

Performance attributes:
Pa = [Pa_1, Pa_2, …, Pa_m]
Where m is the number of Performance attributes.

Capacity attributes:
Ca = [Ca_1, Ca_2, …, Ca_n]
Where n is the number of Capacity attributes.

An example of "Performance attribute" for a wireless handset processor could be the total clock cycles expended by a low bandwidth codec (H.264), for a reference digital video sequence, for a standard resolution and frame rate.

Time Window

These attributes may have different time windows associated with them, for example, performance scaling in the wireless handset processors for digital streaming video applications, could imposes a Performance attribute requirement to handle 56Kbps – 2 Mbps data streams within a period of five years. Similarly, capacity scaling in the case of a wireless network application may have requirement to scale from 1 Million to 2 Million subscribers in a period of five years. The time windows corresponding to the functionality attributes are therefore:

Functionality Time Window:
Tf = [Tfa_1, Tfa_2, …, Tfa_l]
Where l is the number of Functional attributes.

Performance Time Window:
Tp = [Tpa_1, Tpa_2, …, Tpa_m]
Where m is the number of Performance attributes.

Capacity Time Window:
Tc = [Tca_1, Tca_2, …,Tca_n]
Where n is the number of Capacity attributes.

The functionality attributes that are mapped to design parameters have an overall time window Tw, which is the maximum of all individual time windows.

Tw = Max (Max (Tfa_1, Tfa_2, …, Tfa_l), Max (Tpa_1, Tpa_2, …, Tpa_m), Max (Tca_1, Tca_2, …,Tca_n)) (7)

Flexibility Design Space

Through various existing systems engineering methods, like QFD [8] these functionality attributes (similar to requirements) can be related to design parameters. These parameters constitute the flexibility design trade space. The flexibility design parameters vector is therefore:

Dp =[Dp_1, Dp_2, …, Dp_k]

Where k is the number of design parameters that map to the flexible design space. **(2)** It contains all the flexibility design parameters. For example, in a wireless handset processor, if the performance flexibility is realized using a 2X on-chip cache AND an enhanced Direct Memory **(3)** Access (DMA),

Dp =[Dp_1, Dp_2]
Where,
Dp_1 - 2X on-chip cache.
Dp_2 - Enhanced DMA.

Current Costs

The Dp vector is associated with current implementation cost. This cost is comprehensive, and should include the costs resulting form various aspects of the implementation:

- Cost of design
- Cost of manufacturing
- Cost associated with product delays to accommodate for the flexibility design
- Cost associated with the incremental risk added to the system as a whole as a result of the flexibility design

(4)

The result is a flexibility cost vector:
Cf =[Cf_1, Cf_2, …, Cf_k] **(10)**
Where k is the number of design parameters.

(5)

Future Costs

There is a cost vector (in the future) for implementing the **(6)** flexibility option, in other words activating the built-in flexibility features. Note that this is different from the cost of designing flexibility which was described in the previous section. This cost is dependent on the design decisions made at t0, i.e. on the flexibility design parameter vector Dp.

Ci(Dp) =[Ci_1, Ci_2, …, Ci_k] **(11)**
Where k is the number of design parameters.

Value of Flexibility

Along with the cost, there is a value associated with implementing the flexibility. This value can be represented by the vector Vi. This value is dependent on the state of the future.

Vi(F(t), Dp) = [Vi_1, Vi_2, …, Vi_k] **(12)**

Where k is the number of design parameters.

Alternative valuation methods can be used to yield an estimate of product option value, yielding information on the relative value of flexibility options during product design. In [14] an example of wireless handset processor is presented where the value of flexible and fixed options are estimated under certain and uncertain future and found that the value of flexible options increases with increasing uncertainty.

Limitations of NPV

The traditional method that companies use to select which projects or designs to invest in, Discounted Cash Flow analysis (DCF) or Net Present Value (NPV) calculations, does not always accurately represent the actual value of the projects under study [9]. That is because DCF assumes that we will follow a predetermined path. In reality, uncertainty and investment choices exist together and these choices are spread over time. As uncertainty changes, downside losses can be avoided by not investing more funds into projects which have poor performance [10]. In our case, this investment relates to the cost of embedding flexibility in the product.

We use the concept of real options to calculate the call value of the option, based on the earlier work of Black and Scholes. In our case this is the value of embedding flexibility in a product design. This section provides a mechanism to compute the value of the flexibility option Vf (Eq. 12), that is, the value of embedding multi-attribute flexibility in the design.

Real Option Approach

There are multiple methods to compute Vf using Real Option Analysis. Amram and Kalutilaka[12] propose three high level solutions:

- The PDE approach, by solving a partial differential equation to obtain the value of the option from a tracking portfolio.
- A dynamic programming approach that lays out the future and folds back the optimal strategy.
- A simulation approach that picks the optimal value strategy by simulating all possible outcomes.

Black-Scholes Model (PDE)

The Black-Scholes model is simple to implement once all the variables have been identified. It consists of an equation that computes the value of the option given the following variables:

- Cost of exercising the option,
- Current value of the underlying asset,
- Risk free interest rate,
- Time to expiration, and
- Volatility of the underlying asset

Other than ensuring a proper mapping, one needs to verify the boundary conditions of the formula. The Black-Scholes formula [8] for the valuation of financial stocks is the following:

$$\mathbf{V = N(d1)\ A - N(d2)\ X\ e^{-rT}} \quad \textbf{(13)}$$

Where
V = Value of call option
A = Current value of underlying asset
X = Exercise price
T = Time of expiration
r = Risk free interest rate
σ = Volatility of underlying asset
N(d) = Cumulative value of normal distribution at d

$$\mathbf{d1 = \ln(\sigma/X) + (r + 0.5\,\sigma 2)T)/(\sigma.Sqrt(T))} \quad \textbf{(14)}$$
$$\mathbf{d2 = d1 - \sigma.Sqrt(T)} \quad \textbf{(15)}$$

This formula models European call options. European options can only be exercised at the expiration time T. On the other hand, American options can be exercised at any time between t0 and T. In modeling flexibility using real options, although the most accurate model is the American one, we can justifiably use the European model by assuming that at the time of the valuation of the flexibility (design phase), one can predict to a degree of certainty the time at which this flexibility would be activated . This time is Tw as shown in Eq.8.Moving forward with the European model, we can then map the flexibility real options parameters to the financial parameters as shown in Figure 6 Mapping Design Flexibility Options to Financial Options.

Financial Call Option Parameters		Flexibility Option Parameters		Comments
Option value	**V**	Value of designing flexibility	**Vf**	
Option price	**P**	Cost of designing flexibility at time 0	**Cf**	
Exercise price	**X**	Cost at time T of implementing the flexibility	**Ci**	
Current stock price (price of underlying	**A**	Current value of implementing flexibility	**Vi**	The mapping of this variable still needs some careful

asset)				manipulation to ensure that it matches the boundary conditions of the Black-Scholes model
Time to expiration	**T**	Time at which the flexibility would be implemented	**Tw**	To fit the Black-Scholes model, there is an assumption that the time between incurring cost Ci and getting value Vi is zero. In reality, this time is not zero and the equation would have to be adjusted to account for it by time shifting either Ci or Vi.
Risk free interest rate	**r**	Risk free interest rate	**R**	
Volatility of the stock price	**σ**	Volatility of the expected benefit of implementing the flexibility	**σ**	

Figure 6 Mapping Design Flexibility Options to Financial Options

In order to successfully utilize this model, we need to identify a method for computing the risk free interest rate, the volatility of the expected benefit of implementing flexibility and the time to expiation. A proposal for how to assess these parameters is presented in [14]. In this paper we take a closer look at the time to expiration.

Time to Expiration

The time to expiration for a flexible design option is shown in Figure 7 Flexible Design Time Line. This timeline is based on two generation of products – Gen1 and Gen2. The flexibility option is based on the decision to embed flexibility in Gen1, to have the Gen2 Features.

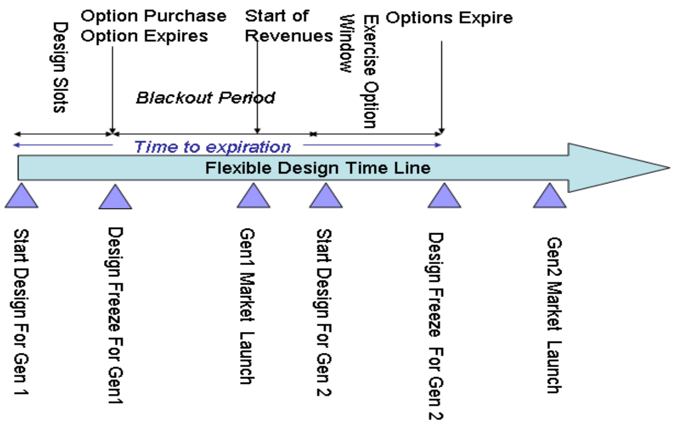

Figure 7 Flexible Design Time Line

The flexibility "slots" have to be designed before the design of Generation 1 is frozen. This is the time when the window to purchase the flexibility option exists. If these slots are designed (based on the cost and value analysis described in the preceding chapters), the decision to "populate' or leverage from this slots can be done at any time before the scheduled freezing of the design of the Generation 2 product. This defines the time to expiration of the flexible design.

Limitations of Black-Scholes

The Black-Scholes formula assumes the existence of a replicating portfolio and no arbitrage [8]. The absence of data on replicating portfolio for flexible options makes the estimation of the value of the underlying asset less accurate. Since flexible product options in innovative industries are not traded on open security markets it is difficult – and often impossible – to find a replicating portfolio for assessing the value of a particular, flexible product feature as a European or American Call Option. The value of the underlying asset can be subjectively estimated [11], but the results of the Black-Scholes formula would not be accurate [13]. The formula, however, can be used for qualitative comparison between different flexibility options and in cases where a similar flexible product is already in the market and the value of the flexibility (and volatility) is known.

Flexibility Strategy

The Flexibility Strategy for a product involves the analysis of the cost and value of embedding flexibility in a product and selecting the optimum flexible design options. Once these options have been selected, the portfolio of real options has to be tracked over time to decide which of these have to be nurtured, exercised or discarded. Nurturing could involve creating market awareness or demand for a feature that has been designed in flexible product. Exercising the option would mean implementing these features or filling the 'flexible slots'. Discarding the option would mean not exercising the option.

Figure 8 Option Steps for a Flexible Design shows the steps in the comparison of a fixed design versus a flexible design. The cost of designing flexibility or the 'flexible slots' is determined by the cost of the steps α, β and γ. These steps could be combined as one for products where these options cannot be separately purchased.. The cost of implementing flexibility or populating the flexible slots is determined by the cost of step δ.

If the value of the module described in Figure 8 Option Steps for a Flexible Design is V^C_M, where:

V is the value for the product configuration C, for the party M.

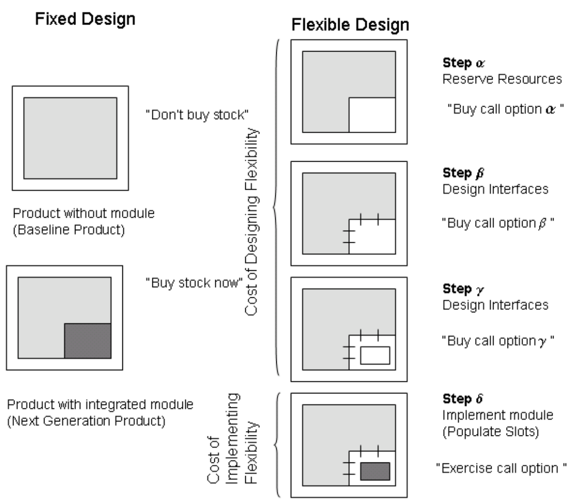

Figure 8 Option Steps for a Flexible Design

M can be customer "C" or enterprise "E" (for this analysis).C is the product configuration, which can be:

0 : without the module

1: with integrated module

α :with reserved resources for module

β : with interfaces with module

γ : with designed module

δ : with implemented module

Value of the module to the customer, Vmod can be expressed as:

$$V_{mod} = V^1_C - V^0_C \quad (16)$$

The cost of the module to the Enterprise is:

For fixed design option, the cost to the enterprise $C_{Fixed,}$ for two generations of the product is -

$$C_{Fixed} = C^0_E + C^1_E \quad (17)$$

For the flexible design option, the cost to the enterprise is $C_{Flex,}$

$$C_{Flex} = C^\alpha_E + C^\beta_E + C^\gamma_E + C^\delta_E \quad (18)$$

The baseline module (first generation only) is recommended when:

$$V_{mod} < \text{Minimum}\,(C_{Fixed}, C_{Flex}) \quad (19)$$

Fixed design is recommended when:

$$C_{Fixed} < \text{Minimum}\,(C_{Flex}, V_{mod}) \quad (20)$$

Flexible product strategy is recommended when:

$$C_{Flex} < \text{Minimum}\,(C_{Fixed}, V_{mod}) \quad (21)$$

Once Flexible product strategy is found to be the optimal strategy, for different features or 'modules', we need to choose the portfolio of options which are optimal and which we would then embed in the product architecture. These options are for different flexibility features.

Option Analysis

To make the optimal decision, we have to choose an optimal set of design options from the flexibility design vector Dp (Eq. 8). This vector has an associated cost Cf (Eq. 10) along with an associated value of embedding flexibility as computed using the Real Options approach, Vf (Eq. 12).
The choice of flexibility options is different from the choice of financial options because the choice of design options would be done at the time of "embedding" flexibility. Once the initial set is chosen, we are restricted to this portfolio of options for all future product strategies. The choice initial set of design vectors would depend on the decision maker's utility profile and external constraints. A recommendation for choosing these options under three different scenarios is provided in [14].

Conclusion

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The flexibility of a system is its ability to meet a changing set of requirements after it has been fielded under new modes of use or changes in its environment. The purpose of this paper was to provide a framework for estimating the value of embedding flexibility in the design of a system and to recommend a strategy based on this value that would enable us to make decisions to choose the flexible attributes and the resources to invest in these attributes for optimum value capture.

Real Options analysis was used to model the payoffs associated with the flexible design options in the face of uncertainty. This approach is more suitable than the Net Present Value (NPV) based analysis which assumes a static view of the market, when in reality, uncertainty and investment choices exist together and these choices are spread over time. As uncertainty resolves, downside losses can be avoided by not investing more funds into projects which have poor performance.

The Real option Analysis of Flexibility, which was explored in detail in this paper can be summarized using general real option reasoning framework [15,14] as shown in Figure 9 General Real option reasoning Framework.

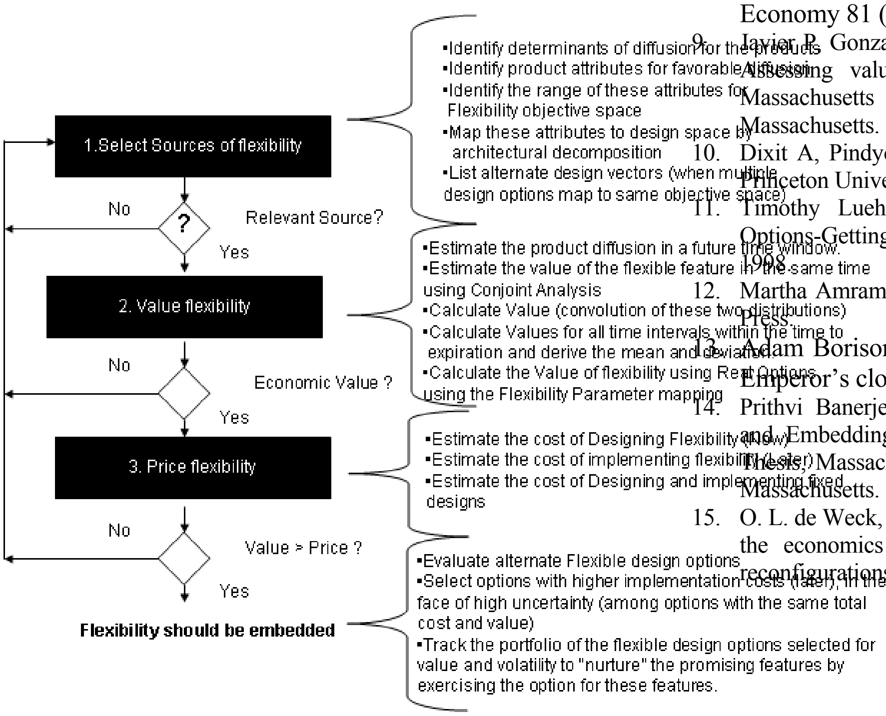

Figure 9 General Real option reasoning Framework[14]

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