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# An Active Support Instrument for Innovation in Deep Uncertainty – the Strategic Management Ingredients in Robotics and Mechatronics

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Abstract

The paper creates the necessary theoretical and applied frame to reduce the unpredictability of the dynamics of innovation, the speed of technological transfer and the speed of reconfiguration/transformation through the integration of systems engineering techniques, dedicated methods for strategic decision making processes and the integration of portfolio management principles in real options with an additional stochastic ingredient expressed by Geometric Brownian Motion (GBM). This new philosophy does not try to find an optimum decision-making in the process of innovation, but contributes to a generalized dynamic prediction on the development of specific mechanism based on flexibility in order to build special dedicated solutions in the field of innovative industries, like robotics and mechatronics. Strategic management ingredients should respond to the challenge of adapting to the typical circumstances of market reactions and the change of the consumer behaviour. Decision making process in high tech industries like robotics and mechatronics is very complex because the technical element should be understand in the relationship with innovators, socio-economic and financial elements. The framework is even more complicated by the market reactions to disruptive technological progress and a very strong global competition. Flexible ingredients in the organizational process offered by concepts like lean manufacturing and Six Sigma are materialized only in a technical manner, but managers in high tech industries are influenced by the need of additional flexibility in order to adapt a quickly respond to changes in markets.


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*Keywords:* Robotics and Mechatronics; Lean; Real Option Analysis; Six Sigma; Geometric Brownian Motion.

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## 1. Introduction

Robotics and mechatronics are innovative industries with an impressive rate of development and in order to obtain the critical output of business is necessary to consider the global view that is beyond the technology and takes into account elements from strategic management. Innovation offers the critical element in this type of industries, but the global picture should include all the elements in their synergic interactions.

The agile manufacturing paradigm is expressed by cooperativeness and synergism by a strategic vision (robust in the processes of change) in the context of strong competition. The paradigm of lean production[1] was introduced in order to obtain flexibility and quality. Lean manufacturing (operational procedures focused on efficient use of resources) is the conventional response to competition with constraints on resources, but agile manufacturing (a strategy that cope with uncertainties) is the response to complexity. Agility is in fact the response to change and it requires cooperation on resources and the flexibility to adapt quickly to markets and clients.

Six sigma takes into account the experience related to complexity and it is based on different methods, tools and techniques associated to Total Quality Management (TQM) and expressed by DMAIC (define – measure – analyze – improve – control). The interest is to support organization's efficiency based on quality (potential and actual), reducing waste, and the active use of cost-cut-in procedures.

As a scientific method, Six Sigma is based on: the observation of critical aspects in markets (related to the business), the development of consistent assumptions related to observation build and test the predictions according the assumptions and observations and a feedback loop that work until the differences between assumptions and real results is minimized[2]. The role of Six Sigma in Supply Chain Management (SCM) should taking into account: the policies on suppliers, the goals and deliverables, the communication strategy, the time table for deployment, the methods of assessing supplier Six Sigma efficiency and the integration of the program.

The difference between Lean Production (based on Toyota system) and Six Sigma is expressed by capability of lean production to improve productivity versus the focus on defects in the case of Six Sigma quality, oriented to reduce *muda* (waste) in any environment. Lean concept offers a proven set of solutions but Six Sigma has the capacity to understand the mechanisms of other problems that appears in the dynamics of innovative processes. In this case the two concepts are complementary and synergic.

The process of innovation is influenced by the strategic management of uncertainties (minimizing versus copping with uncertainties and the balancing between stability and flexibility). The strategic decision should analyze the cost and benefits of reducing/maintaining uncertainties, the optimal exploration of belief system in the firm and the analysis of the anticipated effect in feedback loop architecture. On one hand, the sub-systems need freedom and flexibility in order to cope with uncertainties locally, and on the other hand, the disturbance could be view as opportunities for organizational innovation and change[3,4].

Autonomy (self-determination on goals and rules) should be careful balanced with control (goals determined either autonomously or by other entities). In the literature[5] the interest is to maximize the local control in the context of autonomy distribution according to task correlations and goals. Van de Ven (1976) analyzed the relationship between task uncertainty[6], task interdependence and coordination and Eisenharth (1985) introduced the cost of behavior with outcome measurements[7]. Sitkin (1994) considered that total quality learning is essential in the context of manufacturing flexibility[8]. Orton and Weick (1990) introduced the concept of loose coupling to express the dualism between the technical level, closed to external forces and the institutional level open to external forces[9]. There are different approaches of loose coupling like: motivation through task orientation, the concept of higher order autonomy[10], the possibility of switching between different organizational models[11] and the role of culture in coordination/integration between decentralization autonomy and centralization of values.

In the case of innovation management in high technology industries like robotics and mechatronics, the effects of risk and uncertainty could be exacerbated by the informational asymmetry. Regarding the typical lack of resources in innovation, it is essential to introduce a strong component of strategic management elements in order to understand the adaptability to markets and clients in an efficient manner. Although the strategic deciding responsible owns an extended portfolio of instruments, able to give an integrated image of the complex and social-technical environment in the dynamics view, a universal recipe cannot be applied, since one takes into account the crisis physiognomy unique, the microscopic issues related to the specific actions that need intuition, but also the experience, and especially the flexibility of reconfiguring the decisional process and the progress towards agility.

Beyond the simple understanding of the crisis mechanisms and lessons learned, the strategic management of the crisis situations has been confronting with the lack of practical tools. Such tools should be able to offer the ability of jointing the experienced patterns to the deciding responsible on one hand, and to ensure the agility within the fast reconfiguring of actions that compound the strategy, on the other hand. In order to ensure the critical agility, adapting to unforeseen situations should offer a plus of predictability, observables and controllability features, as well.

The limits of the current approaches derive from the continuous growth of complexity, inability of dynamic allotment and priorities ranking (all of them being important and emergent), as well as from the complex relationships between the human being factor and the automation process, including the inaccurate communication between human being – machine.

Moreover, the effect of technological changes rhythm has exceeded the rhythm of initiating some potential strategies of answering and the essentiality of legislative changes and regulations, thus resulting new involvements as regards the responsibility of transferring, and the inability over the control chain level.

The strategic management in extreme situations signifies the essential factor, no matter the intervention moment. In Figure 1 is represented the continuous adaptation of strategy process in the case of innovation management in a high tech industry.

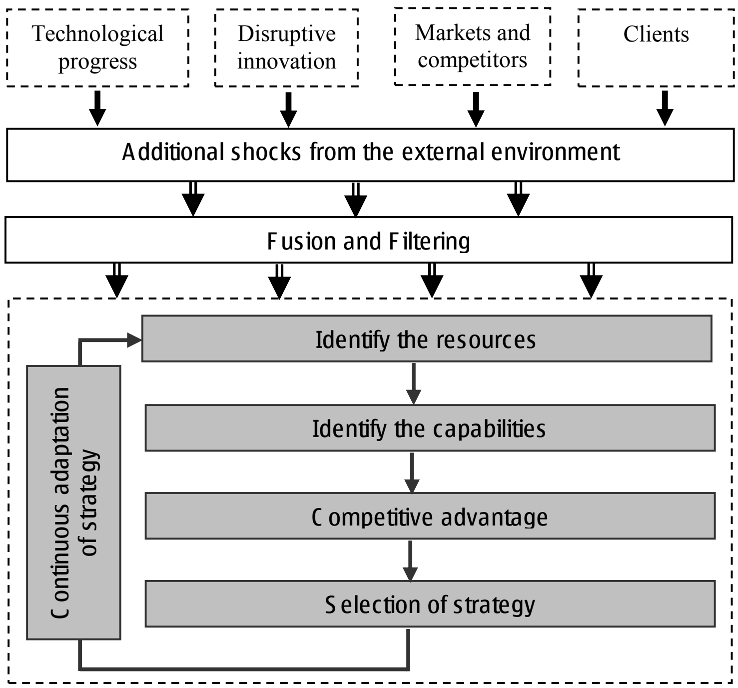


Fig. 1. Resource Based View Model (RBV) for Robotics and Mechatronics

## 2. Emergent objectives for the future research projects in the field of robotics and mechatronics

Although the literature abounds in theoretical patterns and solutions, the management of innovation has been often affected by the lack of some strategic leadership elements, where the manager is run over with data and information that might divert his attention over actions regarding adaptability and agility to respond at market transformation.

The new techniques and tools should typically offer a more generalized algorithm for decision support based on mathematical models, algorithms and decision support tools[12,13], but also it is important to include the inspiration, the experience and the leadership of managers.

The agility that is so necessary during all specific stages of project management in innovative industries can involve work abilities of real options, as extension of the financial options within a frame beyond the markets. The real option has offered the flexibility needed on departure from erroneous ways, and simultaneously allowing the drawing up of pilot projects. If the manager's performance rather involves the monotony of some gradual dynamics having objectives of reducing the essentiality and surprises in the normality periods of time, as regards the special situations (disruptive growth of technology, shocks in markets, features linked to the transformation of consumers behavior), there will be success objectives radically different, and the options and heuristics play a decisive role. In this way, there is an approach that is similar with the entrepreneurs' decision, since a plus of courage, as well as a superior exposal of responsibility are needed, within a frame where managing the knowledge resources support the flexibility within an uncertain and changeable environment. The knowledge based resources (technical, creative and collaborative) have supported the expertise and excellence, meaning those abilities that should be formed and trained within an accurate frame.

This proposal has in view the training and enhancing of strategic deciding representatives, starting from the integration of new management techniques of the extreme risks, based upon the systems engineering (STAMP, STPA), the integration of innovative specific instruments (Real Option Analysis - ROA, Portfolio of Real Option, mixed with GBM, option games, Fuzzy AHP, ANP), the exploitation of recent research results, but also the deep analysis of case studies.

The originality and innovation elements apply to the contributions necessary on creating a new paradigm on defining the strategic decisions in innovative industries like robotics and mechatronics[14] by the help of systems engineering principles. This can be achieved by creating the hierarchy control structures, in order to manage the complex socio-technical systems. These should robust and anti-fragile during the turbulent periods, by adapting STAMP and STPA methods over dynamic management in the process of transformation by including the microscopic issues of the pilot projects, and finally, by the development of innovation management strategies, starting from the principles of portfolio management of real options together with the stochastic elements.

## 3. The integration of Real Options in Decision Making Process in Innovative Industries

The financial option has offered to the owner the right of buying or selling the assets as supporting some prices (strike price/exercise price), until the date of expiration. The flexibility refers to the fact according to which, such action does not involve an obligation, but signifies a right. For instance, the option CALL will offer to the buyer the right of buying the underlying asset, and the net result of such action (the difference between the gross profit and the option price) will be emphasized by means of the payoff diagram. The PUT option offers to the buyer the right of selling (in any moment before the expiration date) the underlying asset, thus offering this time protection, in case of contrariwise progress. The determining factors of the option value refer to the following: the current value of the asset, the variance of the value, the strike price of option, the time to expiration, as well as the risk-free rate. The option pricing theory[15] is based on the concept of replicating the portfolio (composed from the underlying asset and risk free asset, with the same cash flows as the option).

Starting from the financial option, the real options were created, and the main differences could be emphasized in the specialty literature: the underlying is not trading, the variance is not constant and price jumps or other discontinuities might occur or the exercise could not be instantaneous. The financial markets aim towards an approach as regards the perfect market hypothesis, and signify the engine of the new transactional products development. The real options offer the flexibility of decisions related to the real asset. Adapting the financial frame towards the processes of active management will require a thorough study on analogies, by embedding typical microscopic elements, necessary to detail the typical mechanisms of innovation.

The analogy between real and financial options can be emphasized by the following elements: the value of the stock corresponds to NPV; the exercise price to the investment cost; uncertainty and risk free rate are identical[16].

There are different types of real options, some pertaining to use in the proposed applications. The main problems are related to the difficulty to evaluate the project, the impossibility to capture technological shocks that change its value and the difficulty to estimate the mechanics of the specific actions[17].

a) *option to delay* – are used in now or never strategic decisions with only one step and could be viewed as a CALL with the payoff $max\{V-I,0\}$, where $V$ is the exercise price and $I$ the quantity of resources for adaptation;

*b) option to expand/reduce* - is based on the success/failure of the pilot project (small scale action) and will be exercised according to the performance related to the salvage value and proper timing; the manager could expand/ reduce the scale operation and this flexibility could be expressed by a CALL/PUT option;

c) *option to abandon/close* (shut down) operations (and eventually restart) – takes the characteristics of a PUT; the abandonment value change over the life of the stage of the project and it is difficult to apply a conventional valuation;

d) *switching options* – the flexibility is represented by the optionality to re-design operations/course of actions based on the selection of the most efficient effects; at micro-scale actions the rapid switching could represent an interesting short term strategy for the allocations of the resources.

e) *compound options* – a first pilot project of possible actions and is assimilated with a simple growth option; even if the pilot project does not generate a consistent output, the experience could serve in the next steps and actions of the strategy of transformation.

f) *staged option* – could be applied in the phase of recovery and the analytics is similar to compound options.

## 4. The way toward flexibility – the integration of ROA in the processes of innovation

ROA is focused on the opportunities to leverage the performance of a significant fraction of the value of the project (firm). The first aim of ROA is to improve of organization and performance (risk-return in different sets of constraints).

The creation and management of RO incur costs that reduce the global performance of the project. The value of options expressed by flexibility should be trade off with the costs and the understanding the typical mechanisms is critical. In addition, we should consider the influences of the sector (industry) and the psychological elements of the path dependency.

Developing management strategies of extreme situations should take into account the environment elements (uncertainty, volatility, shocks), as well as organizational and management elements (leadership, managerial discretion, the ability of fast interpreting over results achieved by various methodologies ad by agile transposing in real assets).

As regards the literature[18], a series of difficulties on implementing the quantitative models are suggested: approaching the model's hypothesis with the real project hypothesis, determining the essential elements that can be transposed into model variants, by means of carrying out robust analogies and interpretation of results. Such inflexibilities can be found in the real life also, by transposing the assets of impact over flexibility and method's functionality. The complex social-technical involve the use of some psychological factors and essential studies of impact over the resulted borders.

Concerning the crisis management, issues might also occur, relative to the decisional chain, on surprising the analogies able to suggest the management of processes by the help of ROA, the organizational adapting that is able to ensure the options value view. As regards the extreme events, the option value should not necessarily follow a similar way to the classical applications, and ROA implementation might become more and more complicated.

## 5. Portfolios of Real Options – another step for improving flexibility

The strategic deciding representatives own an extended set of opportunities in applications, but also some restrictions of resources allotment, where the financial portfolio perspective[19] is based upon the observation of options interactions on the same supporting asset, fact that involves a simultaneous evaluation of options[20]. Moreover, as regards the proposed application, options should also be analyzed in their interactions environment, by taking into account the succession within the progress edges frame.

The real options are submitted to some additional restrictions (technical or financial), fact that brings new restrictions towards the level of feasibility. PRO signifies a combination of assets and real options, associated to such assets and submitted to a dynamic set of restrictions. In this case, it was proven that analysis should be carried out simultaneously. Markowitz (1952) studied the financial portfolios, based upon the concept of diversification[21] (minimizing the variance for a given return or maximizing the return for a giving variance).

A well-diversified PRO includes the critical resources that could offer an efficient output. The fluctuations in the necessary resources is a critical aspect and it is necessary to diversify the portfolio in order to better adapt to the external situations. PRO should also respond to the problem of negative interactions.

In the case of PRO is considered the variance of returns and the resulting distributions of values of assets. The interest is to obtain the strategies that offer performance in the context of protection from undesirable movements. It results an active attitude in risk management based on exercising real options (in this case the timing is critical) without focus on diversification. Future research should analysis operational and financial hedging strategy[22].

The definition of PRO as combinations of multiple assets and multiple real options based multiple assets, in the context of dynamic constraints leads to increased difficulty in decision-making. The portfolio is influenced by the dynamic interactions (both at real options and real assets) and is not possible to isolate the resulted impact. The management of PRO requires capturing all mechanisms simultaneously.

Building a portfolio should be relevant to the strategy and should support the understanding of the actions impact within the frame of portfolio point of view. Controlling the volatility involvement can be regarded as a way to manage PRO in an optimal way (RO exercised at optimal moments). PRO based management can provide additional information that impacts the global performance, and underlying on this, a dynamics of the processes linked to the innovation in high-tech industries.

## 6. A stochastic ingredient for representing the flexibility offered by options

The integration of stochastic models like GBM in instruments that offers flexibility (RO, PRO) could improve the global picture of the dynamic processes that play a critical role in innovation. The interest is to add elements better represent the real mechanism in the processes of transformation (these processes are very important in innovative industries, characterized by volatility and a high speed of dynamics). The analogy with the option games can offer an interesting approach regarding the timing of actions within the strategy of transformation. If the option of resources allocation is taken as *I*, the equivalent value of saving at the initial time is denoted as $\gamma_{cr}V_0$, thus resulting that $NPV<0$. In this way, a window of waiting will be opened, meaning that a favorable moment of action is waited.

The result of transformation ($p_t$) can be written in the following way:

$$p_t = p_0 \cdot e^{gt} \tag{1}$$

where *r* is the factor of updating, and *g* signifies the innovation based action efficiency:

Therefore, the saving value equivalent to the initial moment becomes:

$$\gamma V_0 = \int_0^t p_0 e^{|g-r|} dt = \frac{p_0}{r-g} \tag{2}$$

which can be written for the moment *T* as:

$$\gamma V_T = \frac{p_T}{r-g} = \gamma V_0 e^{gT} \tag{3}$$

Within such strategy, $NPV_T$ will be represented by:

$$NPV_T = \gamma V_T - I \tag{4}$$

The formulation emphasized in equation (1) seems at first sight as restrictive, but as regards the proposed application, there are typically very fast successions of actions that compose the strategy. Moreover, such demarche will not influence the philosophy of creating a variant on stochastic meaning.

Instead, new optimal rules of intervention result from the above mentioned expression, written in a simple way and which do not need a high volume of data. The optimal timing could be modeled considering that the salvaged value *V* follows geometric Brownian motion (GBM).

In this case the methodology for valuing the option to action consist of:

a. the specification of the salvaged value;
b. the optimization of the intervention strategy based on the payoff function;
c. the analysis of the payoff associated to the optimal strategy of intervention in crisis.

The intervention strategy is a plan of action and could be expressed as a stochastic process $\widetilde{x}_t$. In the case of GBM:

$$d\widetilde{x}_t = (g\widetilde{x}_t)dt + \sigma\widetilde{x}_t dz \tag{5}$$

where *g* is the drift parameter, $\sigma$ the volatility and z is the standard Brownian motion.

Let the expected discount factor:

$$r_0(T) = \left(\frac{x_0}{x_T}\right)^{\beta_1} \tag{6}$$

and it results the following dynamics of strategy (eq. 7).

$$S_0(x_T) = \begin{cases} NPV_T\left(\dfrac{x_0}{x_T}\right)^{\beta_1} & - \quad wait \quad (if \quad x_0 < x_T) \\ NPV_0 & - \quad action \quad (if \quad x_0 \geq x_T) \end{cases} \tag{7}$$

One of the most critical problems that should be solved in real world is related to the mechanisms that contribute to the flexibility of processes in innovation. The dynamics expressed in (7) could offer robust with the strategic management point of view. Future work could be focused on the integration of RBV, dynamic capabilities (DC), transaction cost economics (TCE) on this framework oriented toward the flexibility offered by RO/PRO.

## 7. Conclusions

The understanding of typical mechanisms and processes in innovation is essential in robotics and mechatronics, by using decisional information and models in a practical way, but able to surprise the global view of the efficient reconfiguration of possibilities, and by emphasizing the necessary resources, and taking into account the restrictions, as well. The strategic decision of transformation requires a special complexity transformation, and combining the experience, courage and hunch of manager with data collected from simulations and patterns specific to the decisions, in critical moments, will offer the flexibility and agility of action, so necessary on saving the assets (tangible and intangible) affected by transformation. The uncertainty is not aiming towards finding the optimal feature, since these processes are full of dynamism, and the optimal feature might represent in this situation those decisions taken in useful time.

The main result of the paper is describing the necessary theoretical and applied framework to reduce the unpredictability of the dynamics of innovation. Through the integration of systems engineering techniques, the speed of technological transfers and of potential reconfigurations or transformations is decreased, and can be further improved by investigating the various dedicated methods for strategic decision making processes and the integration of portfolio management principles in real options with an additional stochastic ingredient expressed by Geometric Brownian Motion (GBM).

Using the theory of options might offer the answer on active management of the strategic decisional flow, no matter the stage of the crisis process. The main issue refers to the difficulty of evaluating such options, fact that might lead towards the manipulation of conclusions. The incorporation of the equivalent value of saving is therefore proposed, which refers to the cost of resources in an intuitive way, and which can be transposed under the way of RO and PRO. A new ingredient for a better capturing of real mechanisms is offered by the integration of GBM in this frame based on flexibility (RO, PRO), since this offer a dynamic estimation of the mechanisms related to innovation in conditions of informational asymmetry. The advantage of using the portfolios theory in the situation of real options will allow the continuation of research on the level of typical mechanisms of transformation in the context of limited resources for innovation, the specific volatility of the processes in the field of innovation (results, financial performances).

Another interesting aspect of this contribution is that the architecture of this model is modular and scalable and offers a global but intuitive image over the decisional flow impact during the process of transformation, thus offering the necessary flexibility on finding the convenient moment solutions.

Although the RO/PRO and GBM based model offer encouraging details as regards the dynamics level, studies in the specific field should be carried out, concerning the accurate surprising of assets timing, by taking into account the new behavior of different of external shocks (technological, financial or other types of shocks associated to markets or to the change of consumer's behavior).

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