An Improved model for valuing R&D projects

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Abstract
This paper proposes a theoretical improvement to the Silva & Santiago (2009) valuation model of innovative projects and discusses its practical application. We discuss some points of the model and include a minimum sales function, which decreases in time. In order to test our model, we performed financial evaluation of an existing project. This project has multiple sources of uncertainty and managerial flexibility at every stage of its revision. We conclude from de results that the improved model is the most appropriate for evaluating R&D projects in the context of development product with guaranteed market share.
Keywords: Real option, R&D projects, sales function, dynamic programming.

1. Introduction

Most investments decisions are characterized by uncertainty over their future rewards (HUCHZERMEIER & LOCH, 2001), like R&D projects. However, these investments are very important for companies to remain competitive in their segments. Therefore, it is necessary a correct evaluation of these opportunities. Note that with the wrong method one may sacrifice the long-term health of the firm if he chooses investments that become disappointing over time. Such mistakes could be avoided if the correct method was used for evaluating development projects.

In this sense, this article aims to present a theoretical contribution to the valuation models of R&D research projects and also to propose a practical application. We discusses solutions for temporal uncertainties, technological performance, market requirements and market payoffs during the development of a high technology product in the Brazilian market.

We advance in the application of the decision model introduced in 2001 by Huchzermeier & Loch and improved in 2009 by Silva & Santiago. As the model focuses on managerial flexibility during the development process of a R&D project, the real options approach proves to be the best method of evaluation. In this article, four managerial options were considered at each stage, they are: continue, improve, accelerate or abandon the project.

In order to test the improved model, we studied a real project, which is about developing a network of Power Line Communication (PLC) data transmission, with the

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advantage that the communication infrastructure is already installed. The PLC technology works together with Smart Grid technology in houses and distribution networks. One of the differentials of this technology is that the communication system is hybrid, that is, it uses more than one communication way for information exchange. Furthermore, the PLC modem has not been developed in Brazil so far.

Note that, the Real Option Theory (ROT) emerged from the analogy between financial option and investments in real assets (AMRAM & KULATILAKA, 1999). In finance, an option is a contract that gives the buyer (the owner) the right, but not the obligation, to buy (call option) or sell (put option) an underlying asset or instrument at a specified strike price on or before a specified date[4].

Myers (1977) originally proposed this analogy between real investment and financial options, as well as the term real options. Since then, several works apply the real option methodology for projects evaluation. According to Faulkner (1996), Stewart & Myers (1984) was the first one to suggest applying ROT on R&D projects. The ROT method allows one to do the investment in successive stages and it considers the risk of failure during the project phases (NICHOLS, 1994; SCHWARTZ & MOON, 2000).

Huchzermeier & Loch (2001) adapted the model of Smith & Nau (1995) to evaluate the management of product development projects. The authors presented a dynamic model that is capable of evaluating research projects, which are subject to several sources of uncertainty. They wanted to evaluate the managerial flexibility of R&D projects, since there were few practical evidence on their evaluation. The results showed that increases of other uncertainties, which are not related to the payoff market, might reduce the value of the option. These uncertainties results from operational uncertainties faced by managers of R&D projects.

The paper has three important contributions. First, they identify the main sources of uncertainty of product development projects and they described a suitable model for it[5]. Second, the developed model considers the management of technology development projects and it includes the option to interfere on the course of the project development to achieve better performance. Third, the authors propose the “improve” option, which is an extended of classification of options (such as abandon, expand, contract). This option allows a higher performance level of the product with an additional cost.

In 2005, Santiago & Vakili proposed a change in the initial model. They used three sources of uncertainty (market payoff, performance level and market requirements) and the same model of Huchzermeier & Loch (2001), but with some extra mathematical treatment. In this way, the authors deepened reflections on the model and, according to Santiago & Vakili (2005) they obtained results that are sometimes contrary and sometimes different from those of the above-mentioned paper.

Santiago & Bifano (2005) apply the Santiago & Vakili (2005) model to evaluate a research project that aims to launch an ophthalmoscope on market. The model combines issues of technical, market and cost, which are applied to a research project of a new product.

Finally, Silva & Santiago (2009) insert the stochastic duration of the phases of a product development project in the model of Santiago & Vakili (2005). They considered the time uncertainty and applied the model to the project previously evaluated by Santiago & Bifano (2005). The time of the model was stochastically computed by dynamic programming.

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[4] For more details, see Hull (2003).

[5] The authors perceived five types of uncertainties, namely: the technology performance or the quality of the technological development; the development cost; the development time; the level of market requirement and the payoff market.

The rest of this paper is organized as follows. In section 2, we introduce the improved model of Silva & Santiago (2009). In section 3, we test our model. In section 4, we run some analysis to determine how “sensitive” the model is to changes in the value of the model parameters and to changes in the structure of the model. Finally, Section 5 presents our conclusions.

2. The evaluation model of innovative projects

The improved model described in this section refers to the management of a technology development project that is characterized by a guaranteed market share and by sequential decisions where uncertainty plays a key role.

The evaluation of managerial flexibility is made through Dynamic Programming. This approach is indicated for the evaluation of R&D projects, which have their own characteristics, and whose risk is not correlated with financial markets. On the other hand, the use of dynamic programming raises the question of the appropriate rate to discount the cash flows. However, as the risk of a R&D project depends only on the project’s characteristics, and therefore it is uncorrelated with the market, one can use the risk free rate to precede the discount.

The management model is developed in N stages that correspond to regular reviews of the project. The success at each stage, which is subject to technical and market risks, is measured by the performance of the product. This performance is subject to uncertainties modeled by a one-dimensional parameter x, which is captured by a probability distribution.

In this model, the performance x of the product in each stage follows a distribution independent of past results. Due to contingencies faced by the project, the performance may improve with probability p or it may deteriorate with probability $(1-p)$. The generalization of the binomial distribution allows the performance behavior to be spread over the next stages with the transition probabilities shown in Eq. 1, which is adapted from Huchzermeier & Loch (2001):

$$p_{ij} = \begin{cases} \frac{p}{N}, & \text{if } j \epsilon \left\{ i + \frac{1}{4} + \frac{1}{8}, \dots, i + \frac{1}{4} + \frac{N}{8} \right\}, \\ \frac{1-p}{N}, & \text{if } j \epsilon \left\{ i + \frac{1}{4} - \frac{1}{8}, \dots, i + \frac{1}{4} - \frac{N}{8} \right\}, \\ 0, & \text{otherwise.} \end{cases} \quad (1)$$

Note that the option to continue generates a variation in the transition probability of around 12.5% or 1/8. On the other hand, the option to improvement causes a shift of the probability of transition by 25% or 1/4. These data were obtained from the developers of the R&D project that we will study later.

At each revision stage, j $(j = 0, \dots, N)$, the project is characterized by a development state that will be represented by $Y_j = (x_j, \tau_j)^t$, where x_j is the level of development state that one hopes to reach by the completion of the first j steps of the project and τ_j is the time epoch of the revision.

It is assumed that x_j are random variables that are independent among themselves and independent of revision time (τ_j), for all revision j. The values of τ_1, ..., τ_{N-1}, are obtained by random draws of probability distributions that best fit the case under study, such as the triangular and uniform distribution.

Based on the information of the present stage, the decision (revision) team should choose among the following managerial actions:

- **continue:** it means to follow the project as originally planned;
- **improve:** this option represents the allocation of additional resources in the subsequent stage of development, in order to achieve higher levels of performance at the end of the next stage;
- **abandon:** this managerial action corresponds to the project's interruption. In this case there are no further costs, nor gains.
- **accelerate:** it is similar to the option of improve, this option is characterized by additional resources to achieve a better state of development. Improve in this case means finish the project with a smaller total time. The purpose of this option is to reduce the expected development time and the present uncertainty.

The control option will impact the project's state in the following revision. The next state will be a function of the current state (Y_j), of the applied control (u_j) and of the development uncertainties (ξ_j), in other words:

$$Y_{j+1} = \varphi(Y_j, u_j, \xi_j) \tag{2}$$

Since the next state depends only on the current state, which is represented by independent random parameters, the decision process can be modeled as a Markov decision process. Moreover, the transition of states is additive with respect to the current state and the fraction added will depend on the applied control.

$$Y_{j+1} = \begin{cases} \text{stop}, & \text{if } u_j = \text{abandon} \\ Y_j + \begin{pmatrix} \omega_j \\ t_j \end{pmatrix}, & \text{if } u_j = \text{continue} \\ Y_j + \begin{pmatrix} \omega_j + I_j \\ t_j \end{pmatrix}, & \text{if } u_j = \text{improve} \\ Y_j + \begin{pmatrix} \omega_j \\ t_j - A_j \end{pmatrix}, & \text{if } u_j = \text{accelerate} \end{cases} \tag{3}$$

In Eq. 3, the uncertainty of development is represented by $\xi_j = \left(\omega_j, t_k\right)^t$, where ω_j is a random variable that represents the development uncertainty and t_k is a random variable that represents the duration of the next phase $k = j + 1$. I_j is a constant that represents the expected increase in performance due to control of improvement. The constant A_j represents a reduction in the expected value of the phase duration.

The project's payoff is given by the function $\Pi(y_N) = \Pi(x_N, \tau_N)$, which represents the expected value of a series of profits yielded by the product or technology during its commercial life cycle. The payoff function is described by the Eq. 4. The parameters a and k are respectively the parameters of scale and shape of the function, M is the maximum amount paid by the market for the project outcome, m is the minimum value paid by the market and R is a random variable that represents the requirement of the market at time of launch. For more details, see Silva & Santiago (2009).

$$\Pi(x_N, \tau_N) = \left[(M - m) \cdot exp\left(-\left(\frac{\tau_N}{a}\right)\right)^k \cdot P(x_N \geq R)\right] + m \tag{4}$$

Note that, in Silva & Santiago (2009), the shape and scale parameters of the model are determined by the expected sales observed in the function of sales. The function proposed by the authors is not the most appropriate for research projects financed by agencies or private entities that offer a guaranteed market share for the product, as is the case of the project under study. Therefore, we created a function for the minimum amount of sales that will be inserted in the function of sales. Thus, the new function of sales is shown in Eq. 5.

$$V(t) = \left[(V(k/a)) \cdot (t/a)^{k-1} \cdot e^{-((t/a))^{k})}\right] + v(t)$$
$$v(t) = v - (t/a)^{k} \quad (5)$$

where the constant V represents the largest volume of sales that the market will absorb during the life cycle of the product (t) and v is the lower sales volume during the same period. The Figures 1 and 2 show the displacement of the function $v(t)$ over the life cycle of the product in relation to the parameters of shape and scale respectively.

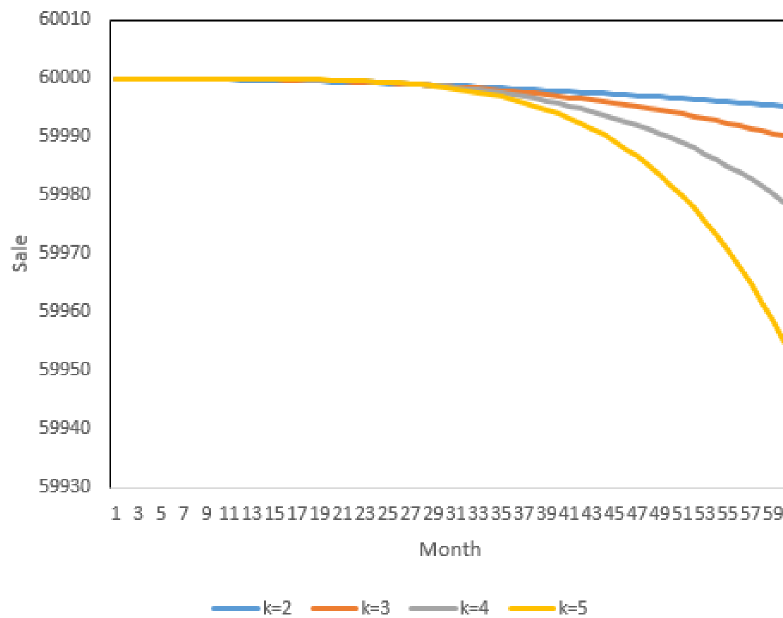


Figure 1 - Variation of $v(t)$ depending on the shape parameter (k), $a = 28$

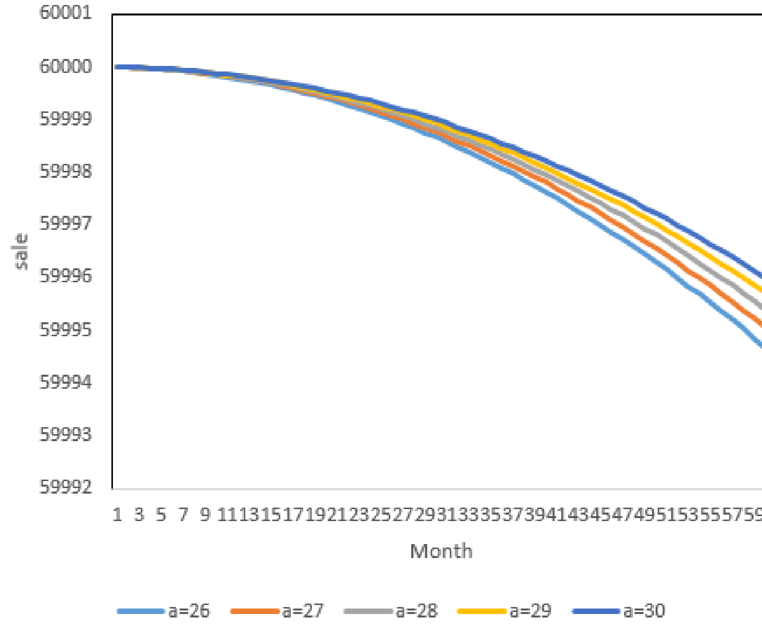


Figure 2 – Variation of $v(t)$ depending on the scale parameter (a), $k = 2$

The development costs may vary at each phase to adjust the model to real situations, where costs are usually increasing in time throughout the phases. Moreover, it is assumed that these costs do not depend on the state of the project's development at the time of revision, but will depend on the phase duration. Thus, the cost may be represented by Eq. 6:

$$C_k(Y_j, u_j, t_k) = \begin{cases} 0, & \text{if } u_j = \text{abandon} \\ K_k(t_k, u_j), & \text{if } u_j = \text{continue} \\ K_k(t_k, u_j) + \alpha_k, & \text{if } u_j = \text{improve} \\ K_k(t_k, u_j) + \beta_k & \text{if } u_j = \text{accelerate} \end{cases} \tag{6}$$

The function $K_k(\cdot)$ represents the cost of the phase k following the stage j $(j = k - 1)$ and varies with its duration, represented in the model by t_k. An additional expenditure α_k or β_k, will occur when the former decision was "to improve" or "to accelerate" respectively. At this point, it is important to note that the cost function is lightly influenced by the change in the duration of the phases. This occurs because only the variable cost is changing over the duration of the stage. The fixed cost remains unchanged. Therefore, this study also aims to generate a rational calculation that fits over the project under study and that captures the sensitivity of variable costs during the development period.

Let $G_j(y_j, u_j)$ be the expected value function generated by applying the control u_j at the state Y_j, which is represented by Eq. 7:

$$G(Y_j, u_j) = \begin{cases} 0, & u_j = \text{abandon} \\ E_{tj}\left[E_{\omega_j|t_j}\left[-C_{j+1}(Y_j, u_j, t_{j+1}) + V_{j+1}(Y_{j+1})|t_j\right]\right] & \text{otherwise} \end{cases} \tag{7}$$

Where V_{j+1} represents the value of the development project at the decision stage $j + 1$ and it is calculated as:

$$V_j(Y_j) = \underbrace{\max}_{u_j \epsilon \Theta} G(Y_j, u_j) \quad (8)$$

where $\Theta = (\text{Abandon, Continue, Improve, Accelerate})$ represents the set of available controls. Finally, when incorporating the bounder condition at the commercialization time, $V_N(y_N) = \Pi(y_N)$, one can write the Dynamic Programming model as:

$$\text{Objective: } V_0 = \underbrace{\max}_{u_0 \epsilon \Theta} G(Y_0, u_0)$$
$$\text{S.T.: } V_N(Y_N) = \Pi(Y_N)$$
$$V_j(Y_j) = \underbrace{\max}_{u_j \epsilon \Theta} G(Y_j, u_j) \quad (9)$$

In this model the calculation of the flexibility value in the R&D projects is made through the Monte Carlo simulation procedure. Once the distributions for τ_1, ..., τ_{N-1} are known, J evolutions are drawn for each of the random variables, obtaining the value τ_0^m, ..., τ_{N-1}^m $(m = 1, \ldots, J)$ for each of them and achieving J lattices tree. Afterwards, one can calculate the costs of abandoning (zero), continue $c(t, \tau_0^m)$, ..., $c(t, \tau_{N-1}^m)$, improving $\alpha(t, \tau_0^m)$, ..., $\alpha(t, \tau_{N-1}^m)$ and accelerate (t, τ_0^m), ..., $\beta(t, \tau_{N-1}^m)$ for each of the random walks patterns. The next step is to proceed the discount with the technique of Dynamic Programming to get the optimal value for each of the nodes of the lattice model, using, for the calculation of expected values, probabilities that are independent of time. It should be noted that the technique of Dynamic Programming is applied for each random generated paths.

3. Empirical evaluation

In order to verify the applicability of the proposals suggested above, we evaluated and tested them in an existing R&D project, the HBDO (a fictitious name to preserve trade secret). This project belongs to a company in the communication technology industry. The generated product is original and there is no similar technology in Brazil.

The increasing of the use and development automation enables the use of Smart Grid technology in houses and distribution networks. However, this technology is not capable of transmitting information by itself, therefore requiring data transmission technologies acting together with it. The PLC modem may be used for this purpose, but in Brazil, this modem is imported and its cost is high.

In this sense, the company Smarti9, *spin-off*[6] maintained by the Regional Center for Innovation and Technology Transfer (CRITT)[7] at Federal University of Juiz de Fora

[6] Means a company that was born from a research group at a university with the aim of exploring a new product or service of high-tech (CRITT, 2013).

[7] The CRITT was created in May 1995 and it is a Center for Technological Innovation of UFJF. The performance of CRITT involves prospecting UFJF projects for entrepreneurs and firms that seek for assistance to develop new products or improve production processes in different areas (CRITT, 2013).

(UFJF), aims to develop a communication system that is hybrid, cooperative, healthy[8] and broadband to form a network of PLC, which uses an already installed infrastructure. This project, the HBDO, receives funding from a private agency that guarantees a market share if the product succeeds in its development. The goal here is to evaluate the technology under a financial point of view; therefore, no further information is given about the project, since it is confidential.

The technological development of the HBDO project was modeled on macro phase, namely:

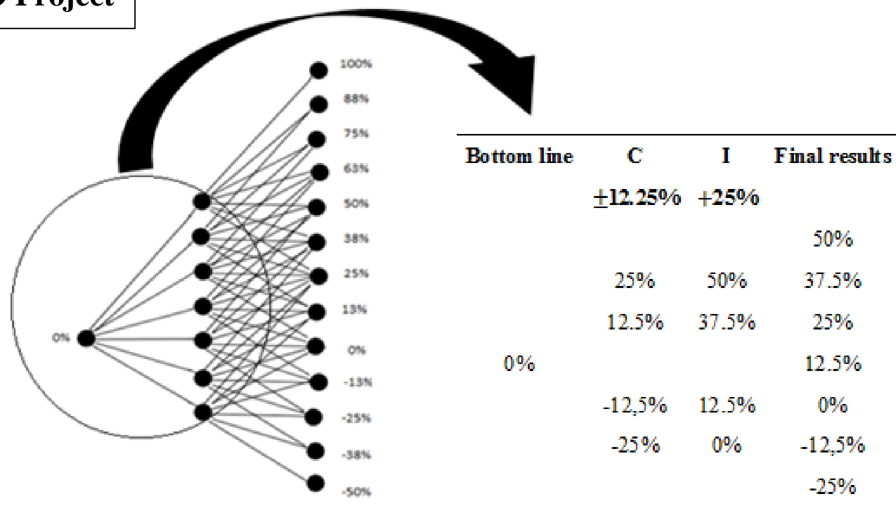
- **Administrative Process:** This phase refers to the bureaucratic process together with the university.
- **Prototype tests:** This phase consists of the first tests to be performed on the product. It is important to examine what will be produced;
- **Product tests:** At this phase, the technology will be converted into a marketable product. In addition, some information and opinions will be collected about the new product.
- **Market launch:** At this phase, the product will be launched on the market. From this moment on, the technology begins to generate a positive cash flow.

It is assumed that the investment on the Process phase is a sunk cost. The first decision point occurs at the end of it. We also assumed that the financial return of the technology does not happen during the product development, only after this.

We decided to evaluate the development of the technological performance using one controllable variable, which is called "reliability". To model the performance evolution, we consider that from one stage to another the product's expected "reliability" would remain as before or improve itself. The variability is about 12.5% to remain or 25% additional otherwise. Thereby the uncertainty tree of the "reliability" parameter points to exceptional performances, such as 100%, for disappointing ones, as -50% (see Figure 3).

To monitor the "reliability" dimension, we consider a binomial lattice and assume that from the period t to $t+1$, the performance may unexpectedly improve with probability p, or it may deteriorate with probability $(1-p)$ because of unexpected adverse events. As Huchzermeier & Loch (2001) we generalize the binomial distribution by allowing the performance improvement and deterioration, respectively, to be "spread" over the next N performance states with transition probabilities. The success probability (50%) was established by the developers of the project. The transition probabilities was 25% (p/N), with two phases evaluation (Prototype and Product).

[8] For the HBDO researchers a communication system is hybrid, cooperative and healthy when the system uses more than one means of communication for exchange of information between devices which can become repeaters and reach a distant node and has a low risk of electromagnetic radiation.



Bottom line	C	I	Final results
	±12.25%	+25%	
			50%
	25%	50%	37.5%
	12.5%	37.5%	25%
0%			12.5%
	-12,5%	12.5%	0%
	-25%	0%	-12,5%
			-25%

Figure 3. Development of technology performance

We evaluated the expected payoff as follows. First we determined a function for sales and estimated the parameters α and k. Second, we calculated the values of M and m. Third, we approximated the required level for "reliability" to a normal distribution[9] with standard deviation $\sigma = 0.4$ and mean $\mu = 0.13$ (the measurement unit was not provided). Fourth, we estimated the duration of the project development. Finally, we got a payoff function for each performance level. However, one should remember that before making the first step, the sales function of HBDO product depends on function of Smart Grid sales. This happens because the technologies of the modem PLC and of the Smart Grid are complementary.

According to Lamin (2013) the installation of Smart Grid technology in Brazil is likely to occur in three consecutive cycles. The first one is what matters for this study and it will occur from 2014 to 2026. The researchers estimate that the PLC modem will be launched in the market in 2016 and have an expected life of five years. Therefore, the PLC modem will be obsolete on 2021. Figure 4 suggests that the HBDO technology will have a peak demand near the 20th month. To construct this figure we adopted the parameters of scale and form as $a = 28$ and $k = 2$, respectively. Moreover, this figure derived from the sales function proposed in this paper.

[9] The values of the normal were defined according to the researchers' expectation. However, sensitivity tests were done to analyze the impact of an increase in standard deviation in the project value. We obtained a negative relationship. This is consistent with Huchzermeier & Loch (2001) results.

HBDO Project

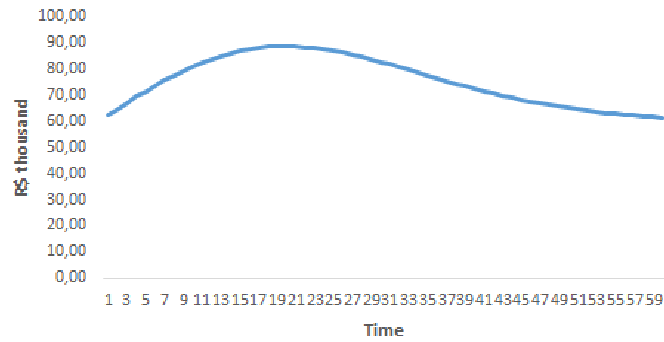


Figure 4. Sales volume

We defined a range of values paid by the market with maximum $M =$ R$ 77.35 million and minimum $m =$ R$ 13.20 million. These values derived from the traditional analysis and they not suffer variation. The developers expect that the development of the project happens in 2 years and 3 months, i.e. one stage of 3 months and 2 stages of 1 year. The payoff function also depends on the market level of requirement, represented by R. That is, the project will achieve a payoff of $\Pi(\cdot)$ by launching the product at time τ into the market if $x_N \geq R$; otherwise, it will receive a baseline payoff m. We consider R to be normally distributed with mean $\mu = 0.13$ and variance $\sigma^2 = 0.16$ and that the product performance is represented by a vector $x = (-0.5, -0.4, -0.3, -0.1, 0.0, 0.1, 0.3, 0.4, 0.5, 0.6, 0.8, 0.9, 1.0)$. Thus, the payoff function is shown in Eq. 10 and its graph is shown in Figure 5.

$$\Pi(x_N, \tau_N) = \left[(77.35 - 13.20) \cdot exp\left(-\left(\frac{\tau_N}{28}\right)\right)^2 \cdot P(x_N \geq R)\right] + 13.20 \qquad (10)$$

HBDO Project

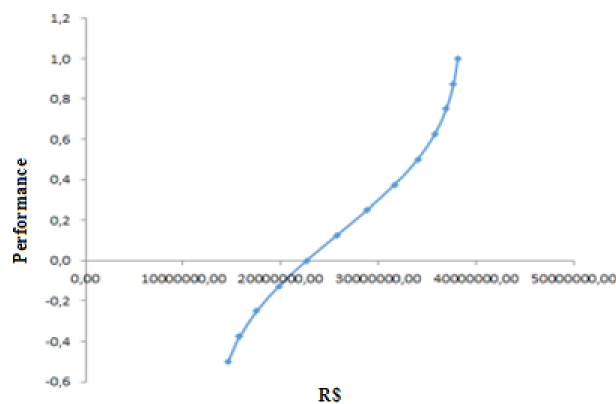


Figure 5. Payoff function - Deterministic Time

The figure above was defined with the expected duration of 27 months. However, the duration of the project development will not be treated deterministically, as is usually done in evaluation models. We admit the possibility of delays and advances. The uncertainty in the duration of the Prototype and Product phases is

modeled as a triangular probability distribution[10]. Each one of these two phases has a minimum of 10 month, maximum of 24 month and mode of 12 month. The minimum duration is about 9 months if the accelerate option is considered. Thus, considering both distributions and the duration of project development, one has $T_P^{min} = 3 + 9 + 9 = 21$ month, $T_P^{max} = 3 + 24 + 24 = 51$ month and $T_P^{mode} = 3 + 12 + 12 = 27$ month. Note that, in spite of the stochastic time, the decision stages are independent upon it.

The percentage of fixed and variable costs was divided according to specific characteristics of each stage (see Table 1). We consider the cost as deterministic or stochastic, depending on the phase and the number of trainees on the project.

Table 1. Duration and costs of each step

Phases	**Time distribution**	**Treatment of time / Cost type**	**Options**		
			Continue	**Improve**	**Accelerate**
Process	-	**Deterministic**	R$ 5.000,00	-	-
Prototype	T(10;12;24)	**Deterministic**	R$ 750.000,00	R$ 40.000,00	-
		Stochastic			
		Fixed	R$ 400.000,00	R$ 40.000,00	R$ 0,00
		Variable (month)	R$ 29.166,67	R$ 0,00	R$ 2.000,00
Product	T(10;12;24)	**Deterministic**	R$ 1.250.000,00	R$ 40.000,00	-
		Stochastic			
		Fixed	R$ 700.000,00	R$ 40.000,00	R$ 0,00
		Variable (month)	R$ 45.833,33	R$ 0,00	R$ 3.000,00
Launch	-	**Deterministic**	R$ 1.500.000,00	-	-
TOTAL	-	**Deterministic**	R$ 2.005.000,00	R$ 80.000,00	-
		Stochastic			
		Fixed	R$ 1.105.000,00	R$ 80.000,00	R$ 0,00
		Variable (month)	R$ 37.500,00	R$ 0,00	R$ 5.000,00

3.1 The evaluation results

We adopted two triangular distributions, which have the following parameters: minimum 10 month, maximum 24 month and mode 12 month, or symbolically T(10, 12, 24). One should note that the minimal duration is 9 months if the accelerate option is exercised. These probabilities refer to the Prototype and Product phases since the Process and Launch phases have deterministic duration.

The costs of the phases are related to their duration. The costs of the Prototype and Product phases are divided between fixed and stochastic costs. All costs of Process and Launch phases are fixed.

We assumed 25% of transition probability ($p = 50\%$ and $N = 2$) and an interest rate at 7% yearly. Moreover for estimating the payoff function we adopted $M =$

[10] As Crespo (2009) we considered the triangular distribution. However, in the case of HBDO, experts believe that the possibility of accelerate is greater than delay.

$R\$\ 77.35$ million, $m = R\$\ 13.2$ million, $k = 2$, $\alpha = 28$, $\mu = 0.13$ and $\sigma = 0.4$. This function is shown in Figure 4. Note that the project payoff increases as the duration of project development decreases and the performance levels increases. On the other hand, the payoff function decreases as time increases and the performance decreases.

HBDO Project

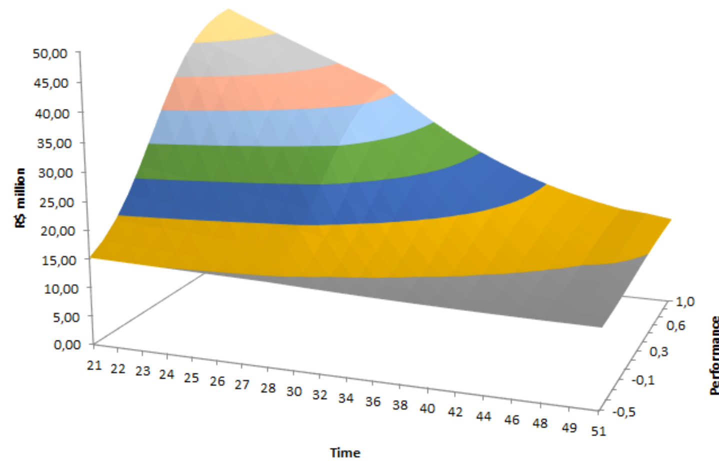


Figure 6. Payoff function - Stochastic Time

We calculated the expected value of the R&D project using the data above. Furthermore, we used the software @Risk for simulate the duration of the project development[11]. The simulations considered a triangular distribution and that the sum of the project phases may not exceed 4 years and 3 months.

The results were achieved by the dynamic programming approach. The estimated value of the active management of the project (ANPV) was R$ 18.71 million. In this case, the improvement option was chosen on the first stage. The project value without flexibility (NPV) was R$ 13.52 million. Thus, the estimated value of managerial flexibility (ANPV-NPV) was R$ 5.19 million.

Figure 7 shows that the distributions of NPVs are significantly positive for the project. This happens because the payoffs of the HBDO project are very high compared to its costs.

[11] We simulated 10 thousand random number. In this case, a graphical representation of the project is meaningless.

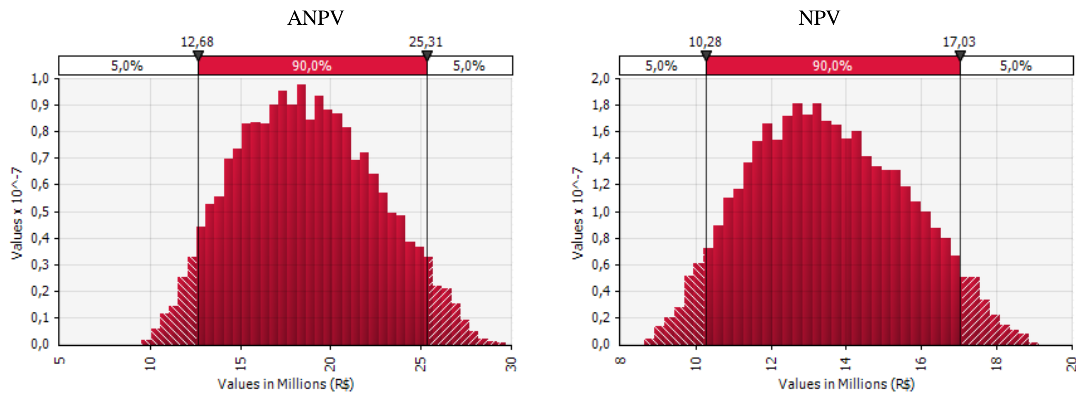


Figure 7. Distribution of NPVs

During the development of the project different scenarios may occur. The prices may change, market requirements and costs may vary and technical difficulties may arise. These uncertainties may spoil the project, which justifies an analysis of their impact on the R&D project.

4. Sensitivity tests on the parameters

We found that the expanded value of the project (ANPV) was R$ 25.32 million without considering the uncertainty of the project duration. This value is 35% higher than the value found previously (ANPV R$ 18.71 million). This result shows that the project is overestimated if one disregard the time uncertainty.

Note that, the treatment of the uncertainties and the choose of the parameters may affect the value of the project. In this sense, sensitivity tests were performed ensuring greater reliability of the results.

4.1 Sensitivity analysis: probability

The success probability is a subjective parameter to the developers and it may be overestimated depending on expectations. Therefore, in this session, we study the effects of probability on the project value and on the flexibility value.

The variation of project value (ANPV) is shown on the right side of Figure 8. The value of the project increases almost linearly with the optimistic view. The variation of the flexibility of the project is shown on the left side of Figure 8. In this case, the value of flexibility decreases as p increases. This occurs because as p increases the chance of the project to generate negative returns decreases and the abandon option, for example, is no longer available.

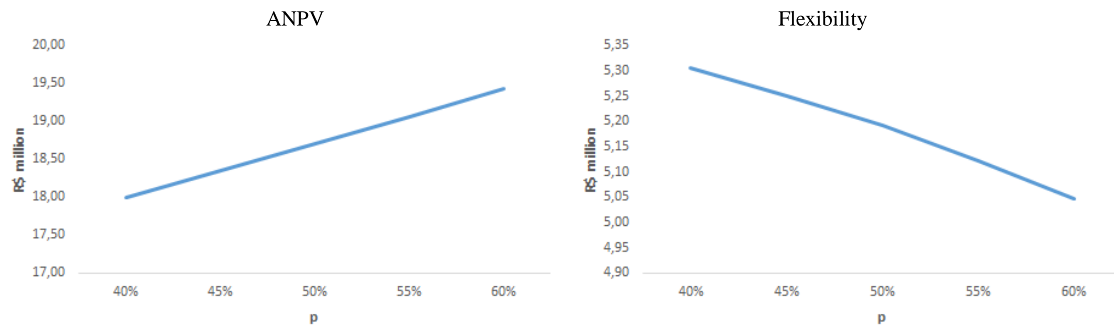


Figure 8. Project value x Flexibility x Probability

4.2 Sensitivity analysis: shape and scale parameters

The determination of the parameters of shape (k) and scale (α) affect the payoff function and, because of this, this section investigates the variation of these constants on project.

Note that, as the scale parameter increases the opportunity window of the project increases. Table 2 shows the variation of this parameter on the project value. One may see that the optimal decision remained the same (Improve – I).

Table 2. The results for the scale parameter (α)

Scenario	Results	Uncertainty		
		Mode deviation	Mode deviation	
			min	max
		0%	15%	100%
$a26k2$	Value	R$ 23.022.901,03	R$ 16.619.471,36	
	Action	I	I	
$a27k2$	Value	R$ 24.176.121,21	R$ 17.594.922,04	
	Action	I	I	
$a28k2$	Value	R$ 25.324.852,65	R$ 18.713.565,80	
	Action	I	I	
$a29k2$	Value	R$ 26.437.583,98	R$ 19.583.753,14	
	Action	I	I	
$a30k2$	Value	R$ 27.502.835,14	R$ 20.561.148,09	
	Action	I	I	

Note: The column of "Mode deviation" indicates the percentage of deviation around the mode of 12 months.

Table 3 shows the effects of the variation of the parameter k on the project value. This parameter is related to the beginning of the opportunity window. The sales of the PLC modem depends on the availability of Smart Grid technology. Thus, an increase in the parameter k increases the value of the project if it has no uncertainty in the time of the development. However, if the project has uncertainty about the phases duration, delaying the beginning of the opportunity window may decrease the value of the project.

Table 3. The results for the shape parameter (k)

Scenario	Results	Uncertainty		
		Mode deviation	Mode deviation	
			min	max
		0%	15%	15%
$a28k0$	Value	R$ 24.165.954,52	R$ 23.921.149,41	
	Action	I	I	
$a28k1$	Value	R$ 24.745.778,74	R$ 21.087.693,93	
	Action	I	I	
$a28k2$	Value	R$ 25.324.852,65	R$ 18.713.565,80	
	Action	I	I	
$a28k3$	Value	R$ 26.138.183,67	R$ 16.898.345,72	
	Action	I	I	
$a28k4$	Value	R$ 27.128.458,05	R$ 15.808.408,01	
	Action	I	I	

Note: The column of "Mode deviation" indicates the percentage of deviation around the mode of 12 months.

Note that in all scenarios the project value without uncertainty was higher than this value with time uncertainty. This fact confirms that the project value is overestimated if one does not consider the time uncertainty.

4.3 Sensitivity analysis: the time uncertainty

Finally, the last sensitivity test was performed on the time uncertainty. The development duration of the modem PLC is important for its survival on market. Thus, we analyzed the impact of time uncertainty on the project value.

It is important to note that the sensitivity test was made with mode of 17 months and a symmetric distribution. This means that we considered the same possibility of accelerate or delay.

We constructed 7 scenarios (see Table 4). The "Half-width" column represents the percentage of deviation around the mode. The "σ_P" column shows the standard deviation of the project duration. The duration of each phase was triangularly distributed.

Table 4. Scenario Results (triangular distribution)

Scenario	Half-width	σ_P	ANPV	Flexibility	Optimal Decision
C1	0%	0,00	R$ 15.522.309,41	R$ 3.712.433,21	Improve
C2	5%	0,49	R$ 15.527.791,98	R$ 3.714.953,60	Improve
C3	10%	0,98	R$ 15.544.708,60	R$ 3.722.856,46	Improve
C4	15%	1,47	R$ 15.573.264,52	R$ 3.737.051,86	Improve
C5	20%	1,96	R$ 15.612.959,56	R$ 3.756.070,11	Improve
C6	25%	2,45	R$ 15.662.758,46	R$ 3.779.964,06	Improve
C7	29%	2,85	R$ 15.712.763,31	R$ 3.804.564,48	Improve

Note: A similar analysis was performed with mode of 12 months. We obtained a close result.

The results show that the expanded value of the project and the flexibility value are sensitive to the variability of the development duration of the phases. However, the optimal decision (Improve) remained the same in all situations, which demonstrates that in this case the optimal action is not sensitive to the variability of the project duration.

Note that the expanded value of the project and the flexibility value are increasing with the variance of the duration of the phases, which is different from the previously results. This happens because we considered now that the mode deviation has the same variability for up and down. In addition, we adopted a mode of 17 month.

At this point, we performed the same test above, but with the phases following a uniform distribution[12]. The uncertainty in the duration of the project was modeled as a uniform probability distribution with minimum of 10 month, maximum of 24 month month, or U(10, 24).

The expanded value of the project was R$ 16.25 million. The best option at the first stage was to improve the project. The project value without uncertainties was R$ 12.18 million. Thus, the value of the managerial flexibility was R$ 4.06 million. Note that this result is 22% lower than the value of the triangular distribution.

We constructed 9 scenarios for test the variability of the duration of the phases (see Table 5). The "Half-width" column represents the percentage of deviation around the mode and the "σ_P" column shows the standard deviation of project duration.

Table 4. Scenario Results (uniform distribution)

Scenario	Half-width	σ_P	ANPV	Flexibility	Optimal Decision
C1	0%	0,0	R$ 15.522.309,41	R$ 3.712.433,21	Improve
C2	5%	0,7	R$ 15.533.455,76	R$ 3.717.717,15	Improve
C3	10%	1,4	R$ 15.567.007,90	R$ 3.733.482,59	Improve
C4	15%	2,1	R$ 15.624.199,70	R$ 3.760.881,31	Improve
C5	20%	2,8	R$ 15.698.123,88	R$ 3.794.008,97	Improve
C6	25%	3,5	R$ 15.806.547,42	R$ 3.849.615,19	Improve
C7	30%	4,2	R$ 15.918.296,28	R$ 3.899.220,74	Improve
C8	35%	4,9	R$ 16.060.313,27	R$ 3.969.792,86	Improve
C9	40%	5,6	R$ 16.228.969,08	R$ 4.051.453,90	Improve

Note: A similar analysis was performed with mode of 12 months. We obtained a close result.

The expected value of the project and the value of the managerial flexibility increases with the variance of the time uncertainty when the duration of the phases follow a uniform distribution. This result is similar to that obtained with triangular distribution.

5. Conclusion

This article aimed to contribute theoretically to the advancement the evaluation of innovative projects, which have many sources of uncertainties, managerial flexibility to treat them and guaranteed market share. We also presented an application of the model on an existent project.

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[12] The continuous uniform distribution is defined by two parameters, a and b, which are its minimum and maximum values. The distribution is often abbreviated $\mathrm{U}(a, b)$. The variance is $\sigma^2 = \frac{(b-a)^2}{12}$.

The model accommodate four main aspects. First, the success of R&D projects depend on the performance level achieved by the technology. Second, the time is treated randomly and the methodology of Monte Carlo Simulation is used to simulate the duration of the phases. Third, the payoff function captures the largest possible amount of variability. Fourth, the sales volume of the product is a decreasing function of time and different of zero.

The application of the model was on the development of a modem PLC of data transmission, which was characterized by many uncertainties, such as phases duration, technological performance, market requirements and product payoff. Furthermore, the project managers had the flexibility to modify the course of the project as new information was emerging and uncertainties resolved.

We used the Monte Carlo Simulation to estimate the duration of the phases of the project. Based on this technique, we generated random values for the duration of the project development. This values were used to calculate the expected value of the project. The results indicated that the expanded value (ANPV) was R$ 18.59 million and that the best option on the first stage was "improve". The value of managerial flexibility was R$ 5.14 million.

Sensibility tests were performed for ensure the reliability of results. We analyzed the variability of the likelihood of success of the parameters of shape and scale and of the time uncertainty. We concluded from the tests that our results are consistent with the literature studied. Besides, we also analyzed the time uncertainty with the duration of the phases following a uniform distribution. The results remained consistent.

In summary, one can say that the main contributions of this work was the adaptation of the model of Silva & Santiago (2009) to evaluate R&D projects in the context of development product with guaranteed market share. In addition, one can see the combination of a lattice tree with Monte Carlo Simulation to treat the variable time randomly and the development of a minimum sales function that decreases in time.

We hope that this work helps one to understand the model described above, which will improve the evaluation of innovative projects that have similar features with those noted throughout this paper.

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