AN IMPROVED MODEL FOR VALUING R&D PROJECTS

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Abstract

We propose theoretical improvement to the Silva & Santiago (2009) valuation model for innovative projects and discuss a practical application. We discuss some points of the model and include a minimum sales function, which decreases in time. In order to test the model, we performed the valuation of an existing project. This project has multiple sources of uncertainty and managerial flexibility at every stage of its development. 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.

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1. **Introduction**

Most investments decisions are characterized by uncertainty over their future rewards (Huchzermeier & Loch, 2001). Investments in R&D projects are important for firms to remain competitive in their industry, and thus, an adequate valuation of these opportunities is necessary if the firm seeks to maximize to its shareholders.

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. Myers (1977) showed the analogy between a financial option and the investment in real assets, and coined the term real options. Since then, several works apply the real option methodology for projects valuation.

According to Faulkner (1996), Myers (1984) was the 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 and Loch (2001) adapted the model of Smith and 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 and managerial flexibility. The results showed that increases of other uncertainties, which are not market related may reduce the value of the project. These uncertainties results from operational uncertainties faced by managers of R&D projects. Their work has three important contributions. First, they identify the main sources of uncertainty of product development projects and they described a suitable model for it. 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.

Santiago and Vakili (2005) proposed a change to this model. They used three sources of uncertainty (market payoff, performance level and market requirements), but incorporate additional mathematical treatment, and obtained results that are contrary from those of Huchzermeier & Loch (2001) in some cases.

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

Finally, Silva and Santiago (2009) add a stochastic duration for the stages of a product development project to the model of Santiago & Vakili (2005). They consider time uncertainty and apply the model to the project previously evaluated by Santiago & Bifano (2005). The time of the model was stochastically computed by dynamic programming.

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

Our model builds on the work of Huchzermeier & Loch (2001) and Silva & Santiago (2009). As the model focuses on managerial flexibility during the development process of a R&D project, the real options approach proves to be the method of choice. Four managerial options were considered at each stage: continue, improve, accelerate or abandon the project.

In order to test the model, we analyze the development of an innovative Power Line Communication (PLC) data transmission network, a technology that operates under Smart Grid technology in distribution networks.

The remaining of this paper is organized as follows: In section 2, we provide a brief review of previous models and introduce our proposed improvement over the Silva & Santiago (2009) model. In section 3 we apply our model to a practical case, and in section 4 we run sensitivity analysis to changes in the value of the model parameters and in the structure of the model. Finally, in section 5 we present our conclusions.

2. Innovative projects evaluation models

2.1 Project management of development of product

Huchzermeier & Loch (2001) proposed a dynamic model of valuation of real options investments capable of evaluating research projects, which have several sources of uncertainty, such as technology and market uncertainty, among others. According to the model the project value (V) can be written as:

$$V = f(\text{performance, cost, time, market, requeriment, market payoff}) \qquad (1)$$

The authors identify 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. In the model, the uncertainties of cost and time are treated deterministically.

Figure 1 illustrates the development stages of an R&D project. Each gate represents a decision point, and is positioned before each stage where a management action is chosen for the following step. The model assumes the technological uncertainty as the probability distribution of the performance of the next stage, which in the figure is represented by the tree branches.

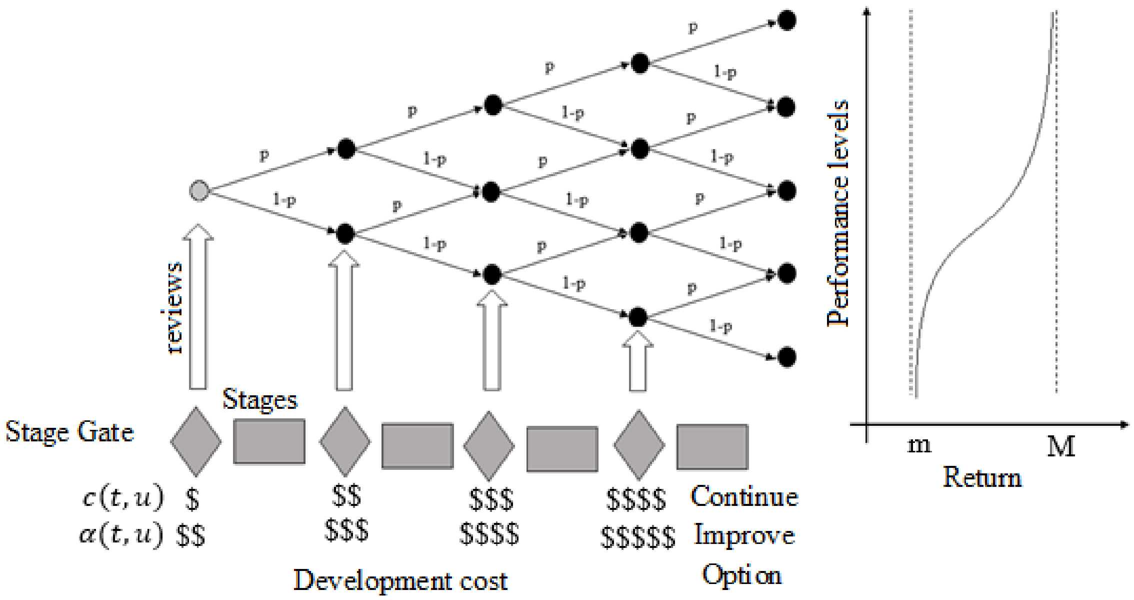

Figure 1 - Schematic representation

Source: Adapted from Huchzermeier & Loch (2001).

At the end of each stage, the project value is given by the market according to the performance achieved by the product during its development process. The chosen action at the point of revision imply different costs and different expected values for the performance of the next stage. Thus, Huchzermeier & Loch (2001) showed with a multistage model, which is solved with the techniques of dynamic programming such that if uncertainty is solved or costs/revenues occur after all decisions are made, more variability may smear out contingencies and thus, reduce the value of flexibility. Besides, the variability may reduce the likelihood of the flexibility to be exercised, which also reduces the value of the project.

2.2 Project management with stochastic time

Silva & Santiago (2009) proposed an alternate approach, in which they consider that the duration of the project is uncertain. They model refers to a technology development project where private uncertainties plays a key role.

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. 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 $(1 - p)$.

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:** follow the project as originally planned;
- **Improve:** allocate additional resources to subsequent stage of development in order to achieve higher levels of performance at the end of the next stage;
- **Abandon:** Interrupt the project. In this case there are no further costs or gains.
- **Accelerate:** 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 $\xi_j = (\omega_j, t_k)^t$, 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).

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

The shape and scale parameters of the model are determined by the expected sales observed in the function of sales shown in Eq. 5.

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

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 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:

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

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.

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.

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:

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

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

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

where $\Theta = (\text{Abandon}, \text{Continue}, \text{Improve}, \text{Accelerate})$ 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:

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

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.

2.3 A contribution to the Silva & Santiago (2009) model

Note that in Silva & Santiago (2009) model, the shape and scale parameters of the model are determined by the expected sales observed in the function of sales presented in Eq. 5. However, 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.

One should note that some organizations such as firms incubated by universities, receive funding from agencies that are interested that they develop a specific product for particular market. Thus, if the product is successful, there will be a guaranteed market for it. This suggests that the product will not be launched in the market with a null volume of sales, as presented in the model of Silva & Santiago (2009). Besides, even after the end of its life cycle it may remain on the market in parallel with any new technology.

Therefore, we created a function for the minimum amount of sales that will be considered in the previous function of sales. The new function is shown in Eq. 10.

$$V(t) = \left[(V(k/a)) \cdot (t/a)^{k-1} \cdot e^{-((t/a))^{k})}\right] + v(t)$$
$$v(t) = v - (t/a)^k \quad (10)$$

The difference is that now the function of the minimum volume of sales is a decreasing function in time, with begin and end different strictly positive. In order to exemplify, Figures 2 and 3 show the displacement of the function $v(t)$ over the life cycle of a product in relation to the parameters of shape and scale respectively. To build the figures below we consider initially the parameters $k = 2$, $a = 28$, $t \in [1,60]$, $v = 60.000$ and $V = 931.764$.

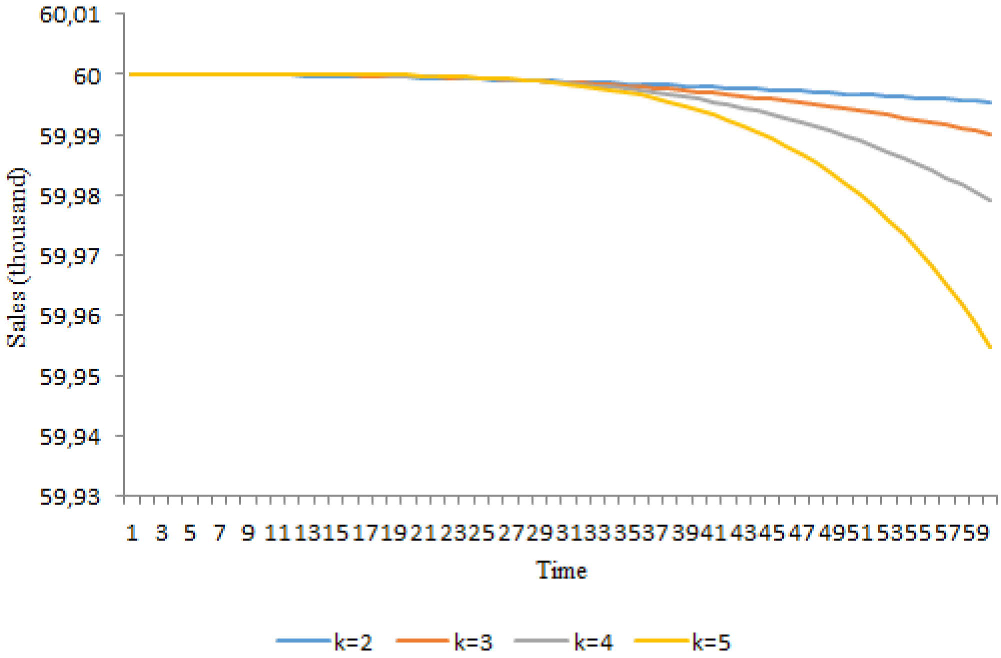

Figure 2 - Variation of $v(t)$ depending on the shape parameter (k), $a = 28$

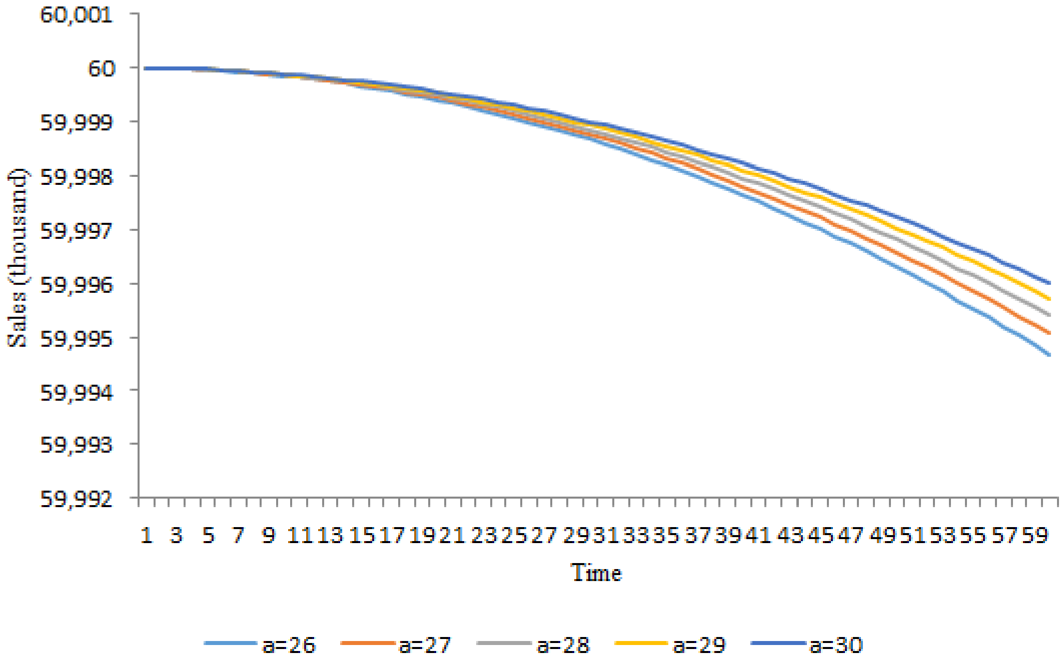

Figure 3 – Variation of $v(t)$ depending on the scale parameter (a), $k = 2$

Note that the minimum function of sales becomes more or less inclined depending on the variations of shape and scale parameters. This change impacts the sales function, as one may see in Figures 4 and 5 below.

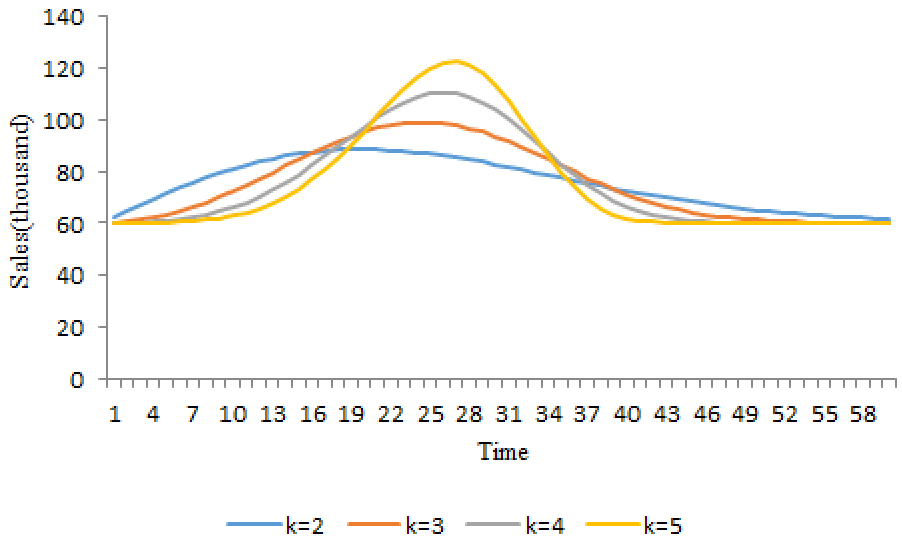

Figure 4 – Variation of $V(t)$ depending on the shape parameter (k), $a = 28$

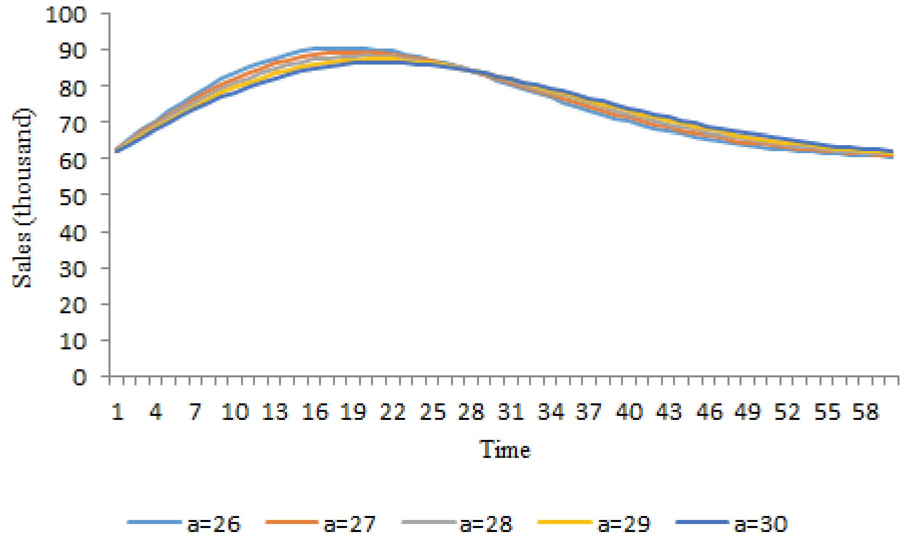

Figure 5 – Variation of $V(t)$ depending on the scale parameter (a), $k = 2$

The payoff function depends on the shape of the sales function, which is determined by the parameters of shape and scale. Therefore, it is necessary to find a best determination of its face.

In order to demonstrate the impact of these parameters on the project value we present an example of a product development project that can be represented by the model described above with a volume of sales given by Eq. (10). The project has three phases, with probability density function of technological uncertainty defined by $x = (-0.5, -0.4, -0.3, -0.1, 0.0, 0.1, 0.3, 0.4, 0.5, 0.6, 0.8, 0.9, 1.0)$, in the last stage. The expected increase in performance is 0.25 units due to the use of the option for improvement (I = 0.25).

The market requirement is a normally distributed random variable with mean 0.03 and standard deviation equal to 2 units. The maximum amount payable by the market (M) is 300 units and the minimum, $m = 0$. The shape parameter (k) is 2 and scale parameter (a) is 10. Other data can be seen in Table 1.

Table 1 - parameters used during the project

Phase	Time	Cost C (fix)	Cost C (var)	Cost I (fix)	Cost I (var)
1	U(2,3;4,5)	1	1.3	3	1
2	U(2,4)	2	2	2	2
3	U(3,5)	3	3	4	3

From this analysis we obtain a NPV of R$ 37.7 and flexibility of R$ 8.0. Now, varying the parameters of shape and scale we obtain the following values (see Figures 6 and 7)

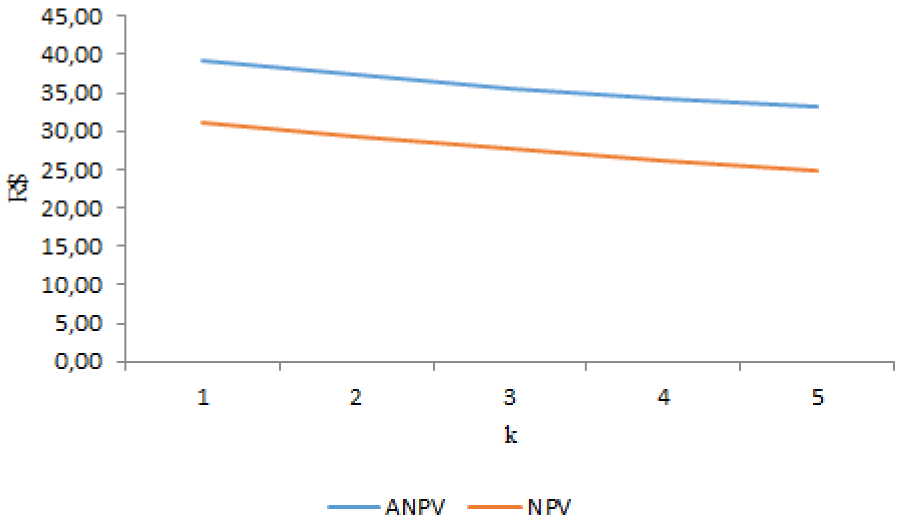

Figure 6 - Variation of NPVs depending on the shape parameter (k), $a = 10$

Note that as the value of k increases, the project value with and without flexibility decreases.

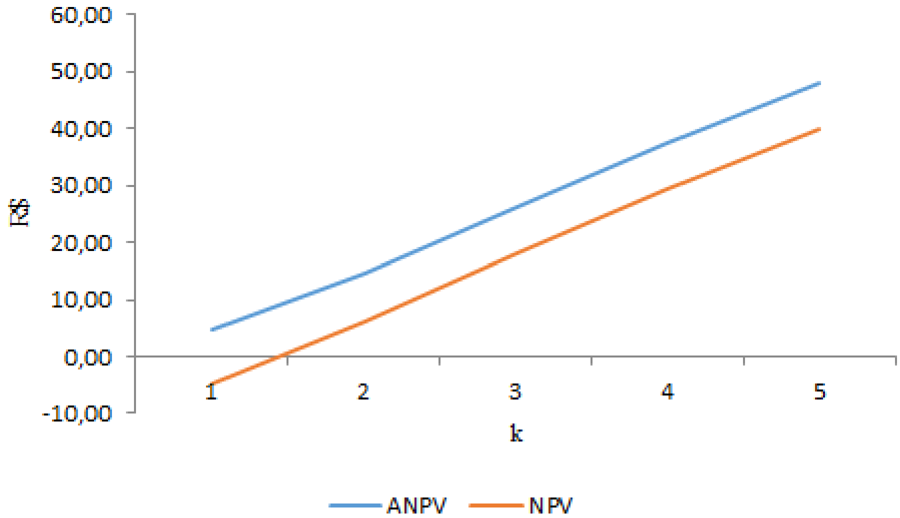

Figure 7 – Variation of NPVs depending on the scale parameter (a), $k = 2$

Lastly, note that as the scale parameter increases, the project value with and without flexibility increases. Besides, depending on the values of this parameter the project value may be negative.

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*[4] maintained by the Regional Center for Innovation and Technology Transfer (CRITT)[5] at Federal University of Juiz de Fora (UFJF), aims to develop a communication system that is hybrid, cooperative, healthy[6] 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 8).

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

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[4] 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).
[5] 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).
[6] 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.

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).

$$p_{ij} = \begin{cases} \frac{p}{N}, & \text{if } j\epsilon \left\{i + \frac{1}{4} + \frac{1}{8}, \dots, i + \frac{1}{4} + \frac{N}{8}\right\}, \\ \frac{1-p}{N}, & \text{if } j\epsilon \left\{i + \frac{1}{4} - \frac{1}{8}, \dots, i + \frac{1}{4} - \frac{N}{8}\right\}, \\ 0, & \text{otherwise.} \end{cases} \qquad (11)$$

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.

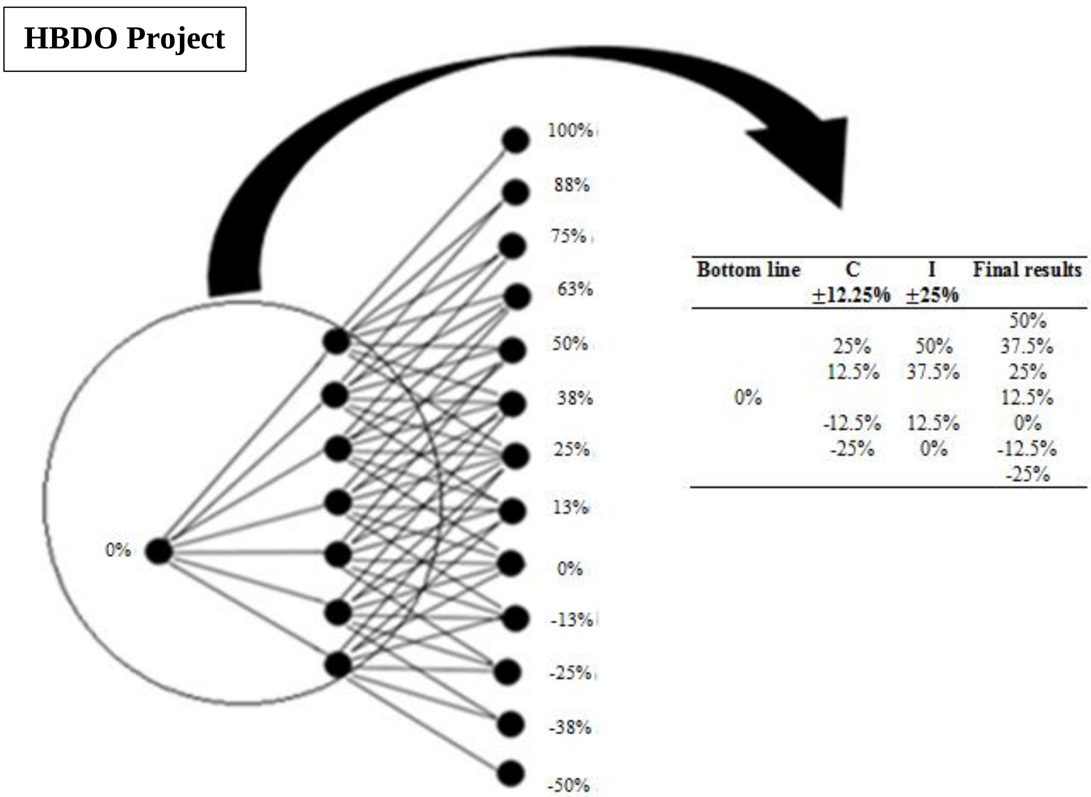

Figure 8 - Development of technology performance

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[7] 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 9 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.

HBDO Project

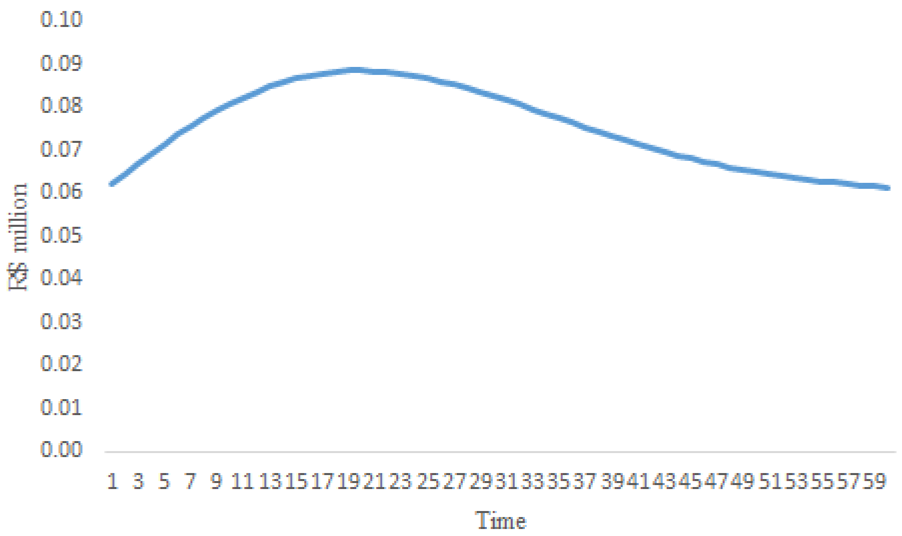

Figure 9 - Sales volume

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

[7] 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.

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. 12 and its graph is shown in Figure 10.

$$\Pi(x_N, \tau_N) = \left[(77.35 - 13.20) \cdot exp\left(-\left(\frac{\tau_N}{28}\right)\right)^2 \cdot P(x_N \geq R)\right] + 13.20 \qquad (12)$$

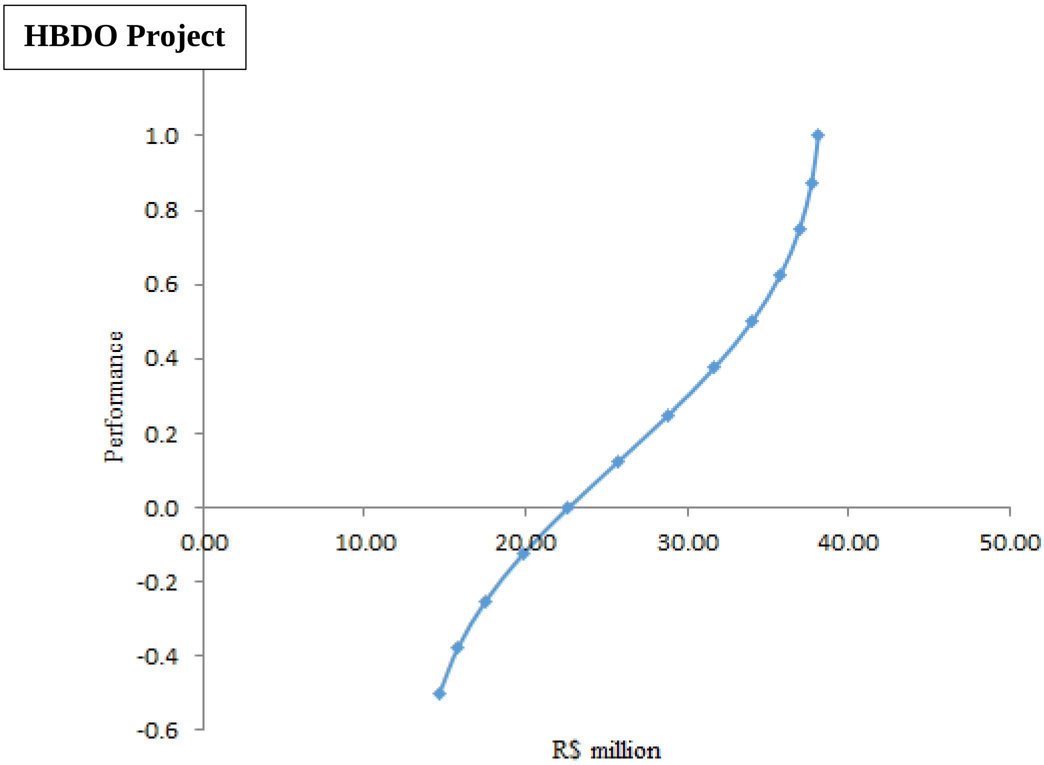

Figure 10 - Payoff function - Deterministic Time

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[8]. 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 2). We consider the cost as deterministic or stochastic, depending on the phase and the number of trainees on the project.

[8] 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.

Table 2 - 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 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 $M = R\$\ 77.35$ million, $m = R\$\ 13.2$ million, $k = 2$, $\alpha = 28$, $\mu = 0.13$ and $\sigma = 0.4$. This function is shown in Figure 11. 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

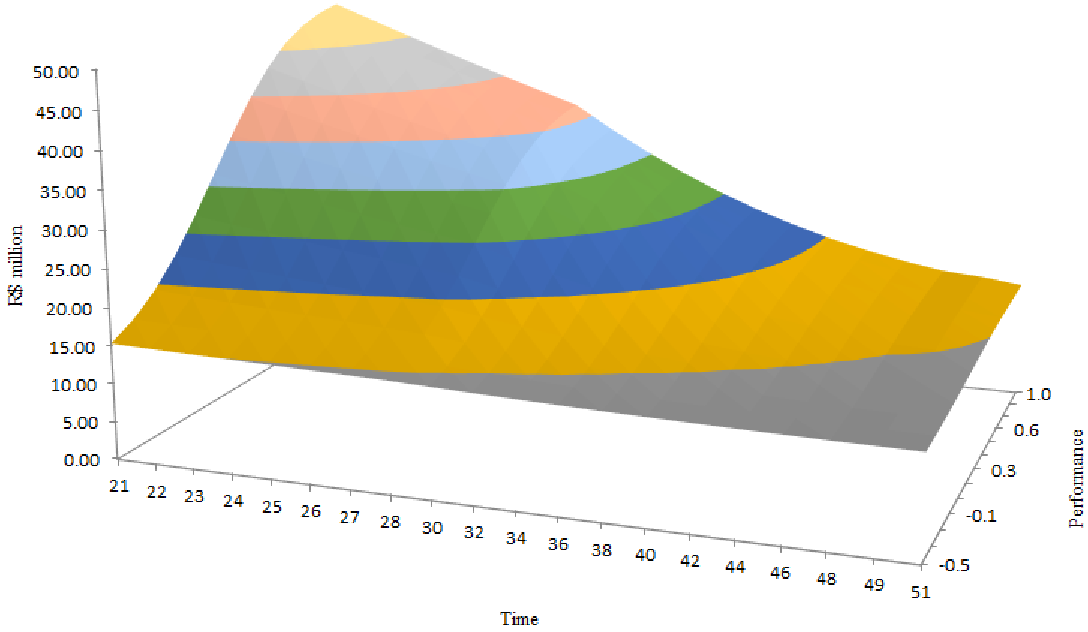

Figure 11 - Payoff function - Stochastic Time

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[9]. 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 12 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.

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

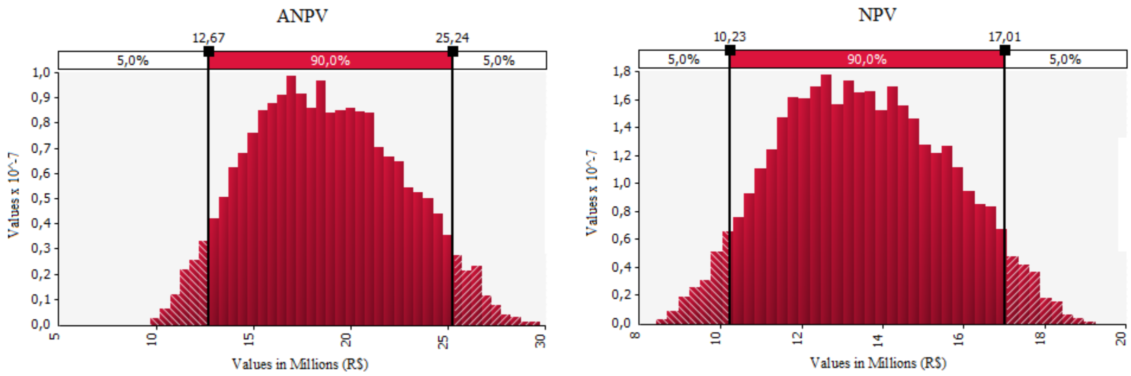

Figure 12 - Distribution of NPVs

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 Analysis

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 13. 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.

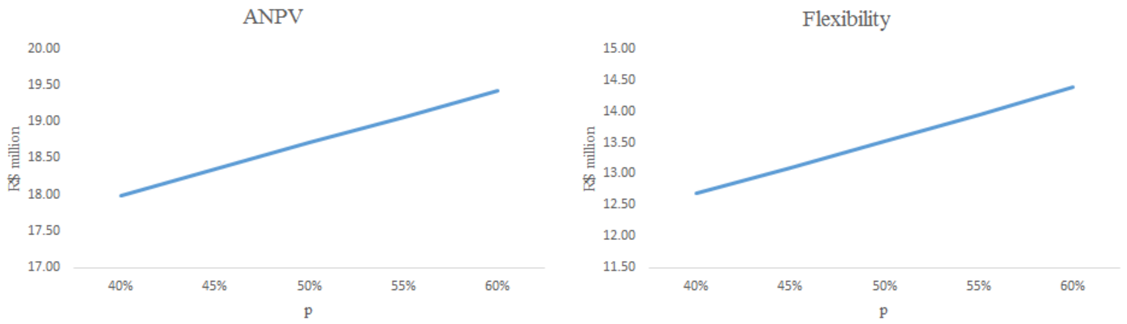

Figure 13 - Project value x Flexibility x Probability

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 3 shows the variation of this parameter on the project value. One may see that the optimal decision remained the same (Improve – I).

Table 3 - The results for the scale parameter (α)

<table>
<tr><th rowspan="4">Scenario</th><th rowspan="4">Results</th><th colspan="3">Uncertainty</th></tr>
<tr><th rowspan="2">Mode deviation</th><th colspan="2">Mode deviation</th></tr>
<tr><th>min</th><th>max</th></tr>
<tr><th>0%</th><th>15%</th><th>100%</th></tr>
<tr><td>$a26k2$</td><td>Value</td><td>R$ 23.022.901,03</td><td colspan="2">R$ 16.619.471,36</td></tr>
<tr><td></td><td>Action</td><td>I</td><td colspan="2">I</td></tr>
<tr><td>$a27k2$</td><td>Value</td><td>R$ 24.176.121,21</td><td colspan="2">R$ 17.594.922,04</td></tr>
<tr><td></td><td>Action</td><td>I</td><td colspan="2">I</td></tr>
<tr><td>$a28k2$</td><td>Value</td><td>R$ 25.324.852,65</td><td colspan="2">R$ 18.713.565,80</td></tr>
<tr><td></td><td>Action</td><td>I</td><td colspan="2">I</td></tr>
<tr><td>$a29k2$</td><td>Value</td><td>R$ 26.437.583,98</td><td colspan="2">R$ 19.583.753,14</td></tr>
<tr><td></td><td>Action</td><td>I</td><td colspan="2">I</td></tr>
<tr><td>$a30k2$</td><td>Value</td><td>R$ 27.502.835,14</td><td colspan="2">R$ 20.561.148,09</td></tr>
<tr><td></td><td>Action</td><td>I</td><td colspan="2">I</td></tr>
</table>

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

Table 4 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 4 - 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 5). 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 5 - 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[10]. 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 6). 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 6 - 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. Conclusions

This article aimed to contribute theoretically to the advancement the valuation of innovative projects, which have many sources of uncertainties, managerial flexibility and a guaranteed market share. We also presented an application of the model to a practical example.

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

The model incorporates 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 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. These 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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