ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 10, Issue, 09, pp. 40462-40471, September, 2020
https://doi.org/10.37118/ijdr.19898.09.2020

RESEARCH ARTICLE OPEN ACCESS

REAL OPTIONS THEORY AND STRATEGIC INVESTMENT DECISIONS: A CASE STUDY IN THE BRAZILIAN WATERWAY SECTOR

João Carlos Félix Souza[1,*], João Gabriel de Moraes Souza[2], Carlos Henrique Rocha[2] and Peng Yaohao[2]

[1]Department of Production Engineering at University of Brasília
[2]Department of Management at University of Brasília - Finance and Quantitative Methods

ARTICLE INFO

Article History:
Received 11th June 2020
Received in revised form
27th July 2020
Accepted 08th August 2020
Published online 30th September 2020

Key Words:
Real options theory,
Managerial flexibility,
Infrastructure investment,
Project evaluation

Corresponding author:
João Carlos Félix Souza

ABSTRACT

The present work is aimed at applying Real Options Theory for the analysis of an investment project related to the removal of the Pedral do Lourenço rock formation, on the Tocantins River waterway in Brazil. A discussion was made as to the merits of this approach for the evaluation of investment projects by decision makers and by incorporating managerial flexibility, especially with regards to the use of public funds, as was the case analyzed by this article. The results indicated that the options to delay and expand provide greater attractiveness than the classic and inflexible net present value approach, leading to the conclusion that the eventual application of those strategies would result in significant increases to the expected profitability of the project.

Citation: ***João Carlos Félix Souza, João Gabriel de Moraes Souza, Carlos Henrique Rocha et al. 2020.*** "Real options theory and strategic investment decisions: a case study in the brazilian waterway sector*", International Journal of Development Research*, 10, (09), 40462-40471.

INTRODUCTION

In Brazil, the deficiencies in infrastructure investment are historic. The lag in investment levels in strategic segments, such as sanitation, energy, telecommunications, and logistics, frustrates the progress of the country's economic activities. According to data from 2017, calculated by Frischtak and Mourão (2018), Brazil has a total infrastructure stock of 36% of its GDP, while it is estimated that full universalization - that is, the adequate modernization of infrastructure - requires a stock of 60%. In analyzing the logistics sector specifically - which encompasses the road, rail and waterway systems - the 2018 Logistic Performance Index (LPI), developed by the World Bank, indicates that Brazilian logistics is, on average, less efficient than that of other emerging countries, though still more developed than other Latin American and Caribbean countries.In a study released by the National Department of Transportation Infrastructure (DNIT, 2019), the portfolio of projects under its responsibility for the period from 2016 to 2019 was estimated at approximately US $ 14.4 billion, a budgeted total which was 38% lower than the US $ 23.2 billion made available to the Department from 2011 to 2015. Analyzing especially the case of waterway transportation, the National Logistics and Transportation Plan (PNLT), which guides investments to be made between 2008 and 2023, recommended a total of US $ 2.4 billion for inland navigation projects for the 2008-2011 period; however, as of 2011, the total investments made represented a mere 22% of the total recommended by the PNLT (CNT, 2018). In the 2016 budget, the amount applied to waterway works reached US $ 750 million (DNIT, 2019), higher than the amount applied during the 2008-2011 period, thus signaling the relevance of waterway infrastructure projects at the national level. Nevertheless, there are still relatively few projects aimed at carrying out improvements and expansions of the nation's waterway network. As elucidated by Villela (2013), Brazil has a waterway transport capacity in volume higher than that currently used and exploited. This full capacity will only be achieved when the sector ensures that the allocation of resources will be made in an intelligent and efficient manner.

Based on this need, the present article aims to evaluate the application of the Real Options Theory approach in order to provide a quantitative analysis of strategic investment decisions, using as an empirical experiment the public project to remove the Pedral do Lourenço rock formation in the Tocantins River waterway. By referencing related works, such as Ronchi, Moura and Rocha (2013) and Carvalho (2015), this study describes the proposed methodology for the economic evaluation of the project, indicating possible adaptations to be made to the environmental variables, for both the related parameters and revenue calculations. In addition, Carvalho (2015) evaluated the economic and financial viability of the Tocantins waterway, considering the transported flow of goods and barges (a) with the presence of the Pedral do Lourenço rock formation, located between Ilha do Bogéa and the municipality of Santa Terezinha do Tauri, in Pará, and (b) with the removal of the rock formation. In order to do so, the Real Options approach was utilized. One of the deficiencies in Carvalho's (2015) study was the consistency presented for the waterway maintenance costs for both alternatives (a) and (b) mentioned above. This article considers a cost function with both fixed and variable components, related to the movement of barges and loads on the waterway. By this method, one can better assess the feasibility of the Pedral do Lourenço project.

In addition to this introduction, this work is organized as follows: section 2 includes a literature review, with discussions on investment projects, economic evaluation of projects, Real Options, and the Monte Carlo method; section 3 presents the programs and actions aimed at the national waterway sector, comparing them with the other modes of transportation, as well as the applied research methodology; section 4 analyzes the proposed model, evaluating the technical and economic feasibility of the project for removing the Pedral do Lourenço rock formation on the Tocantins River, from the perspective of analyzing the Real Options theory. Finally, section 5 presents the conclusion and final considerations.

Literature review and investment decision theories: Based on the theory of investment under uncertainty, according to Dixit and Pindyck (1994), in an investment with productive capacity, there are three important characteristics that must be considered: irreversibility, uncertainty and timing. As previously indicated by Henry (1974), opting for an irreversible decision means reducing for a long period of time the variety of choices that would be possible in the future. However, during an investment process with distinct phases, economic changes are likely to take place, and new information may appear, with the consequences of these unexpected factors generating uncertainty, especially regarding future cash flows. In turn, the timing of the investment is often an underestimated factor: the manager has to decide whether to invest now or wait for better conditions (Quigg, 1993). In this sense, the economic evaluation of projects allows managers to know and estimate the advantages and disadvantages of a project, whether in the public or private sector. Indicators commonly used for project analysis are discounted cash flows (DCF), net present value (NPV), internal rate of return (IRR) and payback (Damodaram, 2006). In the case of transportation infrastructure projects, the Brazilian government requests, in addition to these indicators already presented, the benefit-cost ratio (B/C) and sensitivity analysis (DNIT, 2019). One of the most widely used approaches for evaluating investment decisions is the discounted cash flow (DCF) method, which basically consists of establishing the present value of a series of future cash flows projected over their lifetime, and discounted at a rate representing the opportunity cost of capital applied to the project (Souza, Rocha & Souza, 2018). The projected cash flows are discounted to present value, thus deriving the net present value (NPV), one of the most commonly used valuation metrics for a conventional project, given by the following equation:

$$NPV = -I_0 + \sum_{j=1}^{n} \frac{FCj}{(1+k)^j} \quad (1)$$

where k is the discount rate, n is the project duration horizon, FC_j is the projected cash flow for period j, which can be positive (inflows) or negative (outflows), and I_0 is the initial investment of a project. The NPV has an easy interpretation: when it presents a value above zero, it suggests that the investment is viable in the sense that it brings the expected return to the investor, at the risk level of the discount rate (Macedo & Nardelli, 2008). The Long Term Interest Rate (LTIR) is a nominal rate charged on loans granted by the Brazilian National Bank for Economic and Social Development (BNDES) in order to promote projects for the growth of the country. Most public projects have some financing from the BNDES and, for this reason, it is common to use the LTIR as a discount rate (k) in government projects.

Financial Options and Real Options: An option represents a contract between two parties that gives the holder a right, but not an obligation, to buy or sell a specific quantity of an asset at a contractually established price. According to Hull (2016), there are two basic types of options:

- Call option: offers its holder the right, but not the obligation, to buy a certain asset at a certain date (strike date), for a set price;
- Put option: offers the holder the right, but not the obligation, to sell a certain asset on a certain date, for a predetermined price.

The options can also be of the American, European or Asian types, with pre-established exercise dates. American options are those that can be exercised at any time until the expiration date, and European options can only be exercised on the expiration date. According to Copeland and Antikarov (2002) a financial option gives its holder the right, but not the obligation, to buy or sell a certain asset at a certain date at a predetermined price. Real options, on the other hand, give the right, but not the obligation, to make a decision regarding a real asset, such as investment in research, in the expansion of the business model, in increasing productive capacity, or the abandonment of the business. Real options theory adapts the net present value (NPV) to the context of managerial flexibility, by adding the value of the strategic management option to the traditional NPV, so that the expanded NPV represents the sum of the traditional NPV and the value from managerial flexibility (Trigeorgis, 2000). This decomposition allows for the conclusion that projects can be accepted even if they have a negative traditional NPV (Diwan, 2004), due to the fact that the value of the management flexibility is high enough to convert negative traditional NPVs into positive (adjusted) NPVs. The Real options are classified into mutually exclusive categories, according to the degree of flexibility they provide to the project (Sousa Neto et al., 2008). A basic taxonomy is summarized in Table 1 below.

Investments under uncertain conditions: Black, Scholes & Merton, and the Monte Carlo Simulation: In a classic study developed by Black, Scholes & Merton (1973), a mathematical tool is presented which determines the value of the financial option. In this model, the value of a European *call* option, for example, can be obtained by equations (2), (3) and (4):

$$C_0 = S_0 N(d_1) - X e^{-r_f * \tau} N(d_2) \quad (2)$$

$$d_1 = \frac{\ln\left(\frac{S_0}{X}\right) + \left(r_f + \frac{\sigma^2}{2}\right) * \tau}{\sigma\sqrt{\tau}} \quad (3)$$

$$d_2 = d_1 - \sigma\sqrt{\tau} \quad (4)$$

where C_0 is the call option's value, S_0 is the current price of the stock or underlying asset, N is the cumulative distribution function of the Normal distribution, X is the option's exercise price, e is the Euler constant, R_f is the risk-free interest rate over the life of the option, τ is the time until exercising the option, and σ is the standard deviation of the stock's return. As a complement to the above method, the Monte Carlo Simulation (MCS) allows for the consideration of all possible combinations of variables and, therefore, for analyzing the probability distribution of the project's value (Brealey, Myers & Allen, 2008). To apply this method, it is necessary to determine the probability distribution and its parameters. The process is repeated as often as necessary, and the new NPV values will determine the expected volatility distribution.

The tocantins waterway investment project - pedral do lourenço rock formation

Pedral do Lourenço's regional context: The Arco Norte (Northern Arc) is defined as the transportation system, in its various modes, responsible for the flow of cargo and raw materials by way of ports in northern Brazil, from Porto Velho in Rondônia, through the states of Amazonas, Amapá and Pará, to the port system of São Luís, in Maranhão. Its main focus is on the flow of grains and minerals (CEDE, 2018). In Brazil, the cultivation of grains is a key economic and profit-generating activity. However, such gains are hindered by the lack of infrastructure for the flow of production, as a good portion of the exported grain supply is lost during the process of transferring the product to the main ports (CNT, 2018).

The Center-West region leads the Brazilian agricultural production, and its main destination is the southern Port of Santos. If it were possible to direct all of the outflow to a port in the Northern Arc region instead, the quantity transported could be tripled in the same period of time (CEDE, 2018). According to data from the Ministry of Agriculture (CNT, 2018), this region shipped 8% of the total soy and corn destined for the international market, and in 2019 it already reached more than 25% of the country's total shipments (MT, 2018). There are four water systems in Arco Norte: the Madeiro, the Solimões-Amazonas, the Tapajós and the Tocantins. The Tocantins Waterway starts at its mouth, near the city of Belém (Port of Vila do Conde-PA) and goes to the Peixes Hydroelectric Power Plant (UHE), covering a total of more than 2,000 km (MT, 2009). The potential indicated for this route is a defined extension of 2,000 km, but in 2013 the Ministry of Transportation reduced the commercially usable extension of the Tocantins River to the stretch from its mouth in Vila do Conde-PA to the city of Miracema do Tocantins/TO, near the Lajeado HPP, for a total of 1,230 km, mainly due to navigability restrictions on the upstream stretch from the city of Miracema do Norte/TO to the navigational limit of the Tocantins River at the Peixe HPP (Carvalho, 2015), as shown in figure 1 below:

The national government seeks to deliver an infrastructure project of fundamental importance for the flow of cargo, on the order of 41.1 million tons by 2031, with the stretch of waterway between the city of Marabá-PA and the Port of Vila do Conde being responsible for 32.5 million tons. The other 8.6 million tons will correspond to the agricultural production of mainly soy, soy bran, and corn from MITOPIBA, which corresponds to the states of Maranhão, Tocantins, Piauí and Bahia (Carvalho, 2015). The removal of the Pedral do Lourenço rock formation is essential for the region, since it is the main barrier for reaching the river's expected flow of approximately 80%. The project consists in removing the rock formations that impede the navigation of cargo vessels during the months of September to November, when the river becomes shallower. The completion of the project will allow the Tocantins River to be navigable throughout the year, and with this, the locks in the Tucuruí dam will be able to fulfill their function of allowing vessels to navigate the Tocantins River safely (Carvalho, 2015).

Inflexible NPV calculation: The case study relates to a federal government investment project in the waterway sector, with the discount rate of 6.98% p.a. considered in the NPV calculation, which refers to the Long Term Interest Rate (LTIR), a nominal rate defined as the basic cost of financing granted by the Brazilian National Bank for Social Economic Development (BNDES, 2018).

Definition of the investment's revenue streams: According to Ronchi, Moura and Rocha (2013), waterways are considered to be a sustainable mode of transportation. The currently adopted definition of sustainable transportation covers a myriad of indicators, both environmental (such as air and noise pollution, water consumption, and space required) and social (number of accidents). The authors evaluated this transportation type, and concluded that it has the lowest fuel consumption, as well as the least amount of greenhouse gas emissions - emitting up to six times less than terrestrial modes. As to the potential for accidents, the Brazilian Statistical Transportation Yearbook for the 2010-2017 period, released by the Ministry of Transportation, Ports and Aviation (MTPA) in 2017, indicated the following statistics: 694 railroad accidents resulting in 275 deaths, and 89,400 road accidents, with 55,536 deaths. There was no record of water accidents. Details on the average cost of implementation, operation, social costs, fuel consumption and pollution emissions can be seen in Table 2.

Considering freight and social costs as possible sources of revenue to be appropriated by the government for calculating the return on investment, and by utilizing the Ronchi, Moura e Rocha (2013) and Carvalho (2015) methodology, the proposed revenue equation is:

$$Revenue = R_{freight} + R_{SocialCost} \quad (5)$$

Where $R_{freight}$ is the value (in US$) of reducing the freight difference between terrestrial, or road and rail, and waterway modes, and $R_{SocialCost}$ is the value (in US$) of reducing social costs between terrestrial, or road and rail, and waterway modes. The revenue referring to freight is obtained by Equation 6:

$$R_{freight} = [min(F_{rod}; F_{rod-fer}) - F_{rod-hid}] * Q \quad (6)$$

Where $F_{rod,}$ is the value of road freight, $F_{rod-fer}$is the value of road-rail freight, $F_{rod-hid}$,is the value of road-waterway freight, and$Q_t$is the amount of cargo transported by the waterway(in t). The values considered for the freight calculation were taken from the base study conducted by the Tocantins and Araguaia Waterway Administration (AHITAR), which was published in the governmental feasibility study in 2013, which was the year in which the bidding process was conducted for the Pedral do Lourenço project. That study was considered for the analysis of agricultural demand and freight modes. Freight amounts for the Tocantins-Araguaia Waterway were considered as US$ 0.039/tkm, US$ 0.029/tkm and US$ 0.011/tkm for road, rail, and waterway modes, respectively. For the calculation of the term $R_{SocialCost}$, the following is proposed:

$$R_{SocialCost} = [min(CS_{rod}, CS_{fer}) - CS_{hid}] * Q \quad (7)$$

$$CS_{rod} = D_1 * \alpha_{rod} \quad (8)$$

$$CS_{fer} = D_2 * \alpha_{fer} \quad (9)$$

$$CS_{hid} = D_3 * \alpha_{hid} \quad (10)$$

where D_1,D_2e D_3: are, respectively, the distances traveled by road, rail and waterway modes in order to transport the cargo (in km),$Q$is the amount of cargo to be transported (in t), andα_{rod},α_{fer}e $\alpha_{hid}$are the values of pollutant emissions (in US$/1,000tkm) for the three modes.

The values of $D_i$are defined according to the distance from the origin to the point of embarkation at the seaport responsible for the outflow of production. In the case of road transportation, it is considered as the distance from the origin of the cargo. For rail and waterway modes, we consider the distance of cargo handling by road and the social cost produced by this option, plus the distance of cargo handling by rail or waterway and their respective social costs. The calculation will be similar to the one made to obtain$R_{freight}$.

The values of α for each mode of transportation were defined according to the study conducted by MT and ANTAQ, with values referring to the 2015 calendar year, where the costs of air and noise pollution, water and space consumption, and number of accidents, were accounted for. The cost evaluations, in 2013, are of the order of US$ 32/1000tkm; US$ 7.4/1000tkm; and US$ 2.3/1000tkm, respectively. For the use case of Real Options Theory by public agencies, in order to achieve the optimal levels of planning and expenditure of funds, two types of real options are proposed for the Lourenço Pedral project: delaying and/or altering the scale (expansion). The first proposal is considered due to the inconstancy or lack of continuity of government investments in waterway infrastructure projects. The second should also be considered, as Arco Norte holds the promise of greater efficiency in the flow of products and, if an increase is seen in both agricultural demand and adequate investments in this region, this option will become increasingly realistic and attractive.

Application of the investment methodology - Pedral do Lourenço: The engineering project commissioned by the government consists of stone removal services - by collapsing, in this specific case by utilizing explosives, in addition to signaling the new navigable area and drawing up the electronic navigational charts for a 42 km stretch of waterway. The completion of the work will enable the safe navigation of the Tocantins River for a stretch of over 567 km. For the analysis of this project, the transport of agricultural and mineral loads will be used to estimate the freight demand according to the preliminary surveys and feasibility studies conducted by the relevant government agencies. This data was extracted, for the most part, from reports made available by the MT PNLT (2009), as well as production information given by the local municipalities, as disclosed by IBGE and the Ministry of Agriculture. The project determined that the Marabá - Vila do Conde route would be the main outlet for the extracted crops and mineral ore. The managers defined the use of a type B freighter (Table 3) as an option for cargo transportation, in accordance to the dimensions of the Tucuruí dam lock. The operational capacity considered will be 31,680,000 tons (16 locks/day - channel capacity - *x* 330 days of operation *x* 6,000, which is the capacity of the type B freighter). Finally, in the studies of the alternatives proposed in 2015, the auctioned values varied from approximately US$ 322 million to US$ 13 billion. This difference is due to the complexity of the projects. Some of the alternatives opted for moving freighters with dimensions smaller than the capacity of the Tucuruí dam locks, of 16,000 tons; in others, more advanced engineering technologies were proposed, including the building of crossing and overpassing routes. The value chosen for analysis, given by the result of the public auction, is the lowest (US$ 321,762,724.00).

Investment cost and annual expenditures: The present analysis focuses on the study of the value of the waterway project, and therefore, operational maintenance costs such as routine dredging will not be considered. Besides the investment cost of US$ 321,762,724.00, the annual expense accounted for is of approximately US$ 556,000.00, which corresponds to the maintenance of the installed signaling and the updating of navigation charts (bathymetry).

Revenue sources: The project may be fully financed by the government, provided that the waterway is a viable alternative for the flow of crops and minerals from the region. That is, the social cost needs to be lower than the cost of other modes of transportation: road or road-rail.

Estimated Demand

In order to determine the value for the return on investment, besides the cost, the project revenue stream also needs to be calculated. Accordingly, it is necessary to define the demand for agricultural and mineral shipments that will use the Tocantins waterway as the main outflow of production. For this analysis, the states considered were Maranhão, Tocantins, and Pará. The project's time horizon is 21 years, from 2021 to 2042. The choice of these three states is the result of analyses made by the government itself, which considered the advantages offered by the means of transportation and the

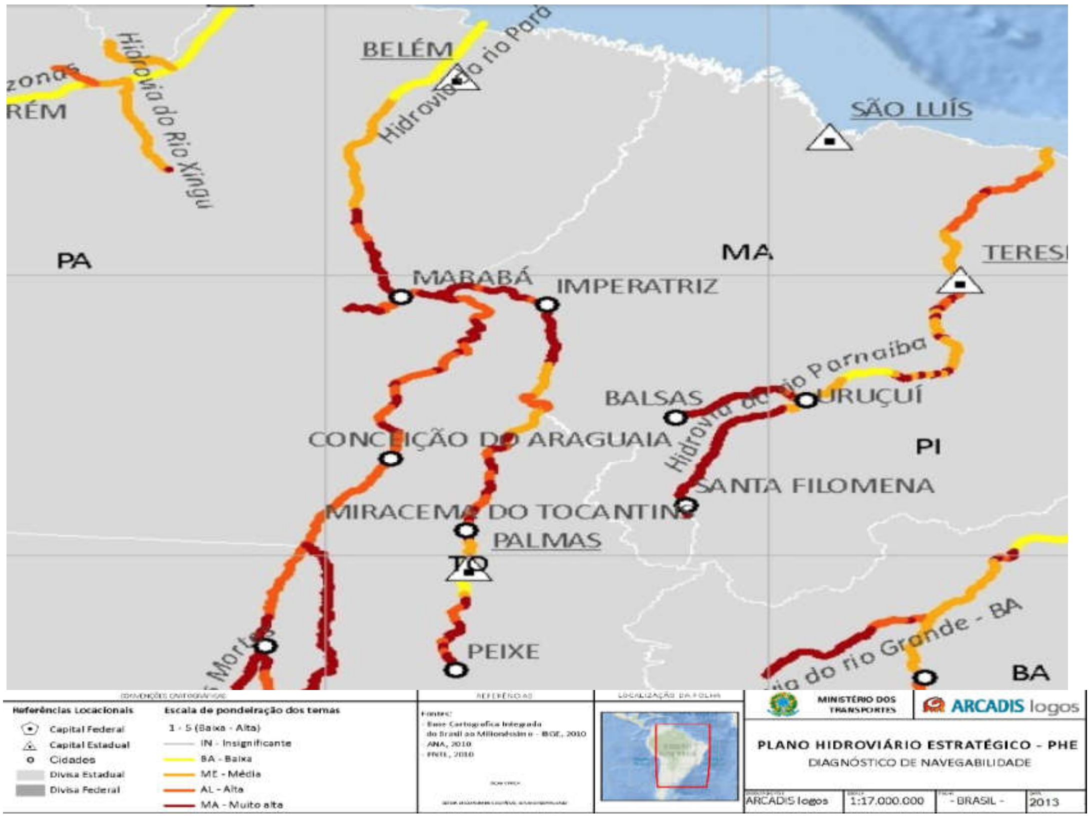

Figure 1: Navigability diagnosis for the Tocantins River, from Vila do Conde - PA to Peixe - TO

Table 1. Real Option Types

Option Type	Description	Applications
Delay or defer	X number of years are given to evaluate if the identified prices justify the implementation and the investment in the project.	Industries related to the extraction of natural resources, real estate markets, exploration of agriculture, construction of transport infrastructure, etc.
Change the scale (expand, contract, stop, and resume)	Considering that the market conditions are favorable and a correct reading of the indications, expansion is possible. In less favorable cases than expected, the operation/investment can be reduced, or even stopped to resume in the future.	Energy industry, contractors, mining, consumer goods industry, long-term investments and investments made in successive stages, road expansions.
Abandon	If market conditions decline dramatically, there is the option to abandon the project permanently and sell all assets and instruments of use.	Capital-intensive industries, airlines, railways, introduction of new products in uncertain markets.
Conversion	Given rapidly changing prices or demands in the market, the manager can alter the portfolio of the production plant, or the inputs needed for production (e.g. due to the high cost).	Energetic, chemical, electronics, or machinery sectors.
Composite	In investments that are made in stages, there is the option to abandon or move on to the next stage, considering the results already achieved and other specific conditions of the moment. In this case, each stage can be considered an option.	Capital-intensive industry, R&D investments in new products, long-term capital-intensive projects.
Growth with multiple interactions	Projects that involve the combination of several options described above.	High technology industries, innovation and investment in R&D, multinational operations, strategic acquisitions, design and business already described above.

Table 2. Comparison between transport modes

Factors/Modal		Terristrial	Railroad	Waterway
Average Implementation Cost (US$/Km)		440,000	1,400,000	34,000
Average Operacional Cost (US$/t/Km)		34	21	12
Social (*) Costs (US$/100 t/Km)		3.2	0.74	0.23
Fuel Consumption (l / t /1,000 Km)		96	10	5
	Carbon hidroxide	0.178	0.129	0.025
Emission of Polutants	Carbon monoxide	0.536	0.18	0.056
(Km/t/1,000 km)	Nitrogen oxide	2.866	0.516	0.149
	Carbon dioxide	0.164	0.0481	0.0334
Infrastructure durability		Low	High	High
Maintenance cost		High	Low	Low

Source: Ministry of Transportation and ANTAQ (2018).
(*) includes accidents, air and noise pollution, water and space needs.

Table 3. Dimensions of the type B freighter and its cargo carrying capacity

Dimensions of the freighter and its cargo carrying capacity	
Total length	150 m
Beam	32 m
Draught	2.10 m
Transport capacity	6 mil t

Table 4. Estimated movement of soybean and iron ore for export through the waterway

	Iron ore (inmil t)	Soy (in mil t)	Total (in mil t)
Year	PAstate	MA, TO and PAstates	
1	3,050	1,427	4,477
2	6,424	1,488	7,912
3	13,540	1,550	15,090
4	14,770	1,616	16,386
5	16,112	1,684	17,796
6	17,576	1,755	19,331
7	19,173	1,829	21,002
8	20,915	1,906	22,821
9	22,816	1,987	24,803
10	24,889	2,071	26,960
11	27,150	2,158	29,308
12	28,962	2,249	31,211
13	30,894	2,344	33,238
14	32,955	2,443	35,398
15	35,154	2,546	37,700
16	37,500	2,654	40,154
17	39,820	2,766	42,586
18	42,285	2,882	45,167
19	44,901	3,004	47,905
20	47,680	3,131	50,811
21	50,630	3,263	53,893

Source: Adapted from DNIT (2013), and MAPA (2013).

main areas with potential use of the Tocantins - Araguaia waterway after the completion of the project. The demanded products considered for the calculation of the DCF, in this study, are soy and iron ore. According to the Ministry of Agriculture, Livestock and Supply (MAPA) for the period 2022-2023, the average growth value for soybeans will be 2.0% per year (on average) to a maximum of 4.22% per year. The optimistic scenario was used to forecast iron ore transportation. The ore was included in the economic viability analysis of the project because the city of Marabá, an export and import center for this mineral, is the largest cargo hub that will utilize the Tocantins waterway, passing through the section of the rock formation to be removed. In Table 4 are the total consolidated values of transported soy and iron ore.

It should be noted that the optimistic scenario in year 14, due to the significant growth in the expected flow of iron ore, relates to an operating capacity of 32,955,000 tons. The report presented by ANTAQ on the performance of the waterway sector in 2017 shows that approximately 395.4 million tons of iron ore were transported between private and public ports (of this total, 46 million were attributed to public ports). The distance considered for cargo movement extends from the city of Marabá to the port of Vila do Conde - PA. This is a public port, and represented 3.22 million (7%) of the overall mineral export volume. The long-term forecast of annual cargo shipments, after the conclusion of the project, is estimated at 32 million.

Freight: Table 5 presents information on the stretch traveled by each mode of transportation in km, the costs of total freight, the reduction of freight cost, and the main product to be moved between the states considered by the study and the city of Marabá-PA, with the final destination being the port at Vila do Conde, using the Tocantins waterway.

Social Cost: The revenue from social costs is obtained by calculating the value of the reduction of the following factors: air pollution, noise, water consumption, space, and number of accidents. Table 6 shows the data used to calculate social costs. For some states, the final values of soy-related social costs are negative, i.e., the waterway mode does not represent the most financially adequate alternative. However, there are others where the social costs, from the hub of origin to the destination port, are not negative. The state of Tocantins, for example, presents these two scenarios.

As the final value of the social costs depends on the projected flow of cargo through the states, demand becomes the main determinant factor. The Gurupi hub in Tocantins, for example, presents the greatest revenue under the aspect of social cost reduction. However, the Balsas hub in Maranhão has the highest freight demand. Ultimately, the positive result of the calculation between social costs and soy demand for the Tocantins and Pará state hubs is not able to offset the negative result of social costs caused by the high demand in the state of Maranhão. Although the results for soybeans are not viable, both the projected demand of iron ore and its positive social cost would lead to the waterway mode being a more favorable option.

Final revenue source values: The final revenue is calculated based on the values previously presented. Table 7 presents the final values of the savings obtained through social costs and freight.

Net Present Value: The project's financial investment plan is US$ 321,762,724.00 (financed by the Government). For the calculation of the net present value (NPV) the Long Term Rate (LTR) of 6.98% p.a. is considered. This is the basic financing discount rate, granted by the National Bank for Social Economic Development (BNDES, 2018). In this analysis, the MCS was used in two instances, in which the *Risk Simulator* tool was used to test the most suitable distributions for the simulation.

The first stage was to define the data volatility, or variance value, for use in the Black-Sholes model. The result was achieved through a further 20,000 iterations, and the normal probability distribution was selected, with mean and standard deviation values based on the demand forecast of the analyzed soybean and iron ore scenarios (Table 8). The variance value by MCS was set to 23.15%.

In the second round, the demand for transportation of soy and iron ore by the states was simulated. This new simulation was composed of more than 80,000 iterations, and was aimed towards avoiding overfitting the model. The normal probability distribution was again chosen according to the transportation demands of soy and iron ore for each state (Table 9). Revenue related to social and freight costs for each year was calculated based on simulated demands. The NPV was achieved from the results of the revenues obtained, from maintaining the installed signage, updating the navigation charts, and from the investment in the project. At the end of the 21-year projection, the value obtained was US$ 679,146,035.40.

Table 5. Reduction of freight cost by using waterways as the main mode for the transported products

State/	Hub	Mode	Distance (Km)			Freight Cost	Cost Reduction
(Product)	City		Road	Rail	Waterway	(US$)	(US$)
Maranhão							
		Road	734			28.55	
(Soy)	Balsas	Road-Rail	268	738		32.29	
		Road-Water	521		567	26.82	1.72
Pará							
	Santana	Road	1007			39.16	
(Soy)	do	Road-Rail	546	738		43.1	
	Araguaia	Road-Water	546		567	27.8	11.37
		Road	479			18.63	
(Minerals)	Marabá	Road-Rail	50	738		23.81	
		Road-Water	50		567	8.51	10.12
Tocantins							
	Miracema	Road	1144			44.5	
(Soy)	do	Road-Rail	418	731		37.92	
	Tocantins	Road-Water	576		567	28.96	8.95
		Road	1376			53.51	
(Soy)	Gurupi	Road-Rail	651	731		46.98	
		Road-Water	576		567	28.96	18.01

Table 6. Social cost reduction by utilizing waterways as the mode of transport for the main products

State/	Hub	Mode	Distance (Km)			Social Cost	Cost Reduction
(Product)	City		Road	Rail	Water	(US$)	(US$)
Maranhão							
		Road	734			23,456.46	
(Soy)	Balsas	Road-Rail	268	738		14,018.35	
		Road-Water	521		567	17,951.97	-3,933.61
Pará							
	Santana	Road	1007			32,180.74	
(Soy)	do	Road-Rail	546	738		22,902.41	
	Araguaia	Road-Water	546		567	18,750.89	4,151.52
		Road	479			15,307.42	
(Ore)	Marabá	Road-Rail	50	738		7,051.72	
		Road-Water	50		567	2,900.20	4,151.52
Tocantins							
	Miracema	Road	1144			36,558.85	
(Soy)	do	Road-Rail	418	731		18,760.18	
	Tocantins	Road-Water	576		567	19,709.60	-949.42
		Road	1376			43,972.88	
(Soy)	Gurupi	Road-Rail	651	731		26,206.17	
		Road-Water	576		567	19,709.60	6,496.56

Table 7. Figures related to the final savings achieved by the use of waterways

Goods	Savings – Freight and Social Costs US$
Iron Ore	4,161.64
Soy - Maranhão	- 3,931.89
Soy - Tocantins_Gurupi	6,514.58
Soy - Tocantins_Miracema	-940.47
Soy - Pará	4,162.88

Table 8. Determination of variance and normal probability distribution - mean and standard deviation of analyzed loads

Evaluated products (in mil t)		
Normal distribution	Soy	Iron ore
Mean	2,226.37	27,485.52
Standard deviation	567.42	13,390.45

Table 9. Demand simulation. Normal probability distribution - mean and standard deviation of analyzed freights

Evaluated demands (in thousand t)				
Normal distribution	Maranhão	Pará	Tocantins	
Cities			Gurupi	Miracema do Tocantins
Mean	1,585.47	45.90	386.75	208.25
Standard deviation	404.08	11.70	98.57	53.07

Table 10: Details on the values obtained by the Black & Scholes method - option to delay. Expanded NPV values (in US$)

Year	1	2	3	4	5	6
RO: PV	-	132,664	5,465,401	26,354,701	62,767,265	109,632,700
NPV	- 251,772,065	- 272,870,936	- 233,812,243	- 188,859,600	- 140,113,155	- 89,043,358
NPV + RO PV	- 251,772,065	- 272,738,272	- 228,346,842	- 162,504,899	- 77,345,890	20,589,342

Table 11: Value of the real option to delay in year 5

r_F	Risk-free rate	6.50%
t	Time for option to expire (Years)	5
X	Project's execution cost (US$)	321,762,722.00
P	Project's Present Value (US$)	183,928,675.00
σ2	Variance for the project's rate of return	23.15%
d1		0.3201
d2		-0.7557
N(d1)		0.6256
N(d2)		0.2249

Value of the real option to delay in year 5: US$62,767,264.80

Table 12. Value of the real option to delay in year 6

r_F	Risk-free rate	6.50%
t	Time for option to expire (Years)	6
X	Project's execution cost (US$)	321,762,722.00
S	Project's Present Value (US$)	235,369,077.00
σ2	Variance for the project's rate of return	23.15%
d1		0.6549
d2		-0.5236
N(d1)		0.7437
N(d2)		0.3003

Table 13. Value of the real option to expand in year 14

r_f	Risk-free rate(Selic)	6.50%
t	Time for option to expire (Years)	14
X	Project's execution cost (US$)	415,500,542.00
S	Project's Present Value (US$)	656,375,912.60
σ^2	Variance for the project's rate of return	23.15%
d1		1.6596
d2		-0.1405
N(d1)		0.9515
N(d2)		0.4441

Value of the real option to expand in year 14: US$550,264,299.44; Value of the expanded VPL isUS$ 466,161,638.62

The Black & Scholes Model: The options to delay and expand will be evaluated, considering a traditional waterway investment project.

Option to Delay: In the Brazilian context, delays related to government projects are common. Environmental and legal aspects, as well as a lack of budget, are common justifications presented by the authorities when the execution does not follow the determined schedule. There are cases of delays of public works in the most diverse Brazilian sectors - for example, in the transportation, energy and health sectors. In an attempt to mitigate these aspects, studies are needed to determine the value of delaying certain investment projects. The calculation of the deferral option is obtained using the Black & Scholes model, which required knowledge of five main elements: 1) risk-free interest rate (r_f); 2) the option's expiration date (τ); 3) the cost of exercising the option (*X*); 4) the current project's value (*S*); and 5) the variance for the project's rate of return(σ^2). According to the proposed model, the value of the risk-free rate to be considered is the Selic rate of 6.5% (6/2019); the value of exercising the option is given as the cost of the project itself, of US$ 321,762,724.00; the current value of the project is the present value of the expected cash flow of the delayed project; the discount rate corresponds to the LTR (6.98% p.a.), which is related to the option's expiration date. The volatility is 23.15% variance. Table 10 presents the values found for the option to delay. The results obtained indicate that the option to delay only becomes feasible and advantageous, from a financial point of view, from the sixth year onwards. From this period on, the demand for soy and iron ore exports will be high enough for a satisfactory return on investment. If those responsible for the project decide to postpone the project for a shorter period, this decision will result in monetary loss. Tables 11 and 12 present the values used to calculate the option to delay for the fifth and sixth years.

Option to Expand: The capital investment in the project for new services that will allow for increasing the area suitable for waterway navigability, with the purpose of allowing greater movement of freight, will only occur if the operational limit of the route is achieved. According to the aforementioned data, the demand for cargo flow will reach its limit in the fourteenth year. The construction period lasts one year, and the same estimates from the option to delay are considered, except the value of the project as the price to exercise the option ($415.50 million), and the current price of the project as the present value of the expected cash flow of the expanded project. Table 13 below presents the data and results of the expansion option.

Conclusion

This paper discussed the use of the Real Options theory for the financial and socio-environmental feasibility analysis of investment projects, presenting its relevance in contexts of uncertainty and of incorporating managerial flexibility in decision making. In particular, an empirical analysis was conducted for a project that makes use of public funds, represented by the waterway investment project concerning the removal of the Pedral do Lourenço rock formation on the Tocantins Waterway. After developing the necessary steps up to the application of the Black-Scholes-Merton method, the use of Real Options proved to be coherent in determining the implementation of the project, for both the postponement and expansion options. The calculation of the result was based on a forecast of export demand for soybeans and iron ore, in addition to freight savings and social costs to be achieved by choosing the waterway mode of transportation. A relevant point to be raised is that when choosing these parameters, the result related to soybeans does not configure a financially advantageous scenario for the implementation of the Pedral do Lourenço removal project. This conclusion is explained by the negative combined values obtained from final freight costs, social costs, and soybean demands in the states of Maranhão, Tocantins, and Pará. In the case of soybeans, railways become the most advantageous mode of transportation.

This result can be interpreted considering the projection of soybean production in the state of Maranhão and, to a lesser extent, in Tocantins: the former presents an yearly gain in prominence in the Brazilian context as a major soybean producer - the city of Balsas, for example, is known as the "city of soybeans" for presenting optimal climatic conditions for 80% of the cultivation of the grain in the state. Likewise, in the state of Tocantins, soy production is also growing: in 2017 the state reached the highest volume of production and export ever recorded, with over 50% growth compared to 2016. In these two states, the road-waterway mode of freight transportation features a higher percentage to be traveled by road, which is, among the given modes of transportation, the most expensive and worst option from an environmental perspective. This situation may be different in the future if the government prioritizes, for example, the construction of roads that shorten these routes. Another solution would be to replace part of the road route with railroad infrastructure. Although the railroad mode is not the most environmentally friendly alternative, it is still better than the most widely used mode today, the highway. The question is that so far, the Pedral do Lourenço removal project is undergoing a new phase of study, and the work is expected to be concluded in 2022. On the other hand, there are also projects directed to the construction of railroads in the region of Arco Norte that are apparently in more advanced stages, such as the Paraense Railroad and the North-South expansion. As can be seen, these two construction projects would serve to direct the goods to the ports of Pará, and thus can be considered more viable alternatives for the outlet of goods. In addition, the Carajás railroad concession was renewed. As a result of this renewal, the federal government allocated investments to the railroads through the creation of the National Railroad Development Fund (FNDF). The state of Pará will have priority in investments in the new fund, in order to ensure the connection between Açailândia (MA) and Barcarena (PA), connecting the North - South Railroad to the port of Vila do Conde. As proposals for future developments, we suggest further research regarding the inclusion of new parameters for the analysis of this project - such as, for example, the issue of maintenance -, as there is currently no definitive data on the costs of road maintenance, nor on the service life of the transportation infrastructure. A further suggestion is to expand the study of demand in addition to agricultural and mineral products, as the execution of the project evaluated in this study will also play an important role in the flow of livestock, which would in turn result in the addition of this variable to the viability calculations. The opinions expressed here are the sole responsibility of the authors, notwithstanding the fact that the implementation of such improvements is also dependent on environmental authorities.

REFERENCES

ANTAQ - Agência Nacional de Transportes Aquáticos 2016. *Estatístico aquaviário 2015*. [online]http:// portal.antaq. gov.br/wp-content/uploads/2017/0 3/Apresenta% C3%A7%C3%A 3o-do-Anu%C3%A1rio-Estat%C3% ADstico-2015.pdf.

ANTAQ - Agência Nacional de Transportes Aquáticos 2018. *Desempenho do Setor Aquaviário: estatístico 2018*. [online]http://portal.antaq.gov.br/wp-content/uploads/2019/02/Anu%C3%A1rio-2018-Layout-4-3.pdf.

BLACK, F., & SCHOLES, M., 1973. The Pricing of Options and Corporate Liabilities. *The Journal of Political Economy*, 813, 637-654.

BNDES - Banco Nacional de Desenvolvimento Econômico e Social, 2018. *Taxa de Juros de Longo Prazo – TJLP e TLP.*[online]https://www.bndes.gov.br/wps/portal/site/home/financiamento/guia/custos-financeiros/taxa-juros-longo-prazo-tjlp.

BREALEY, R. A., MYERS, S. C., & ALLEN, F. 2008. Brealey, Myers, and Allen on real options. *Journal of Applied Corporate Finance*, 204, 58-71.

CARVALHO, E.B., 2015. *Proposta Alternativa de Avaliação Econômica Aplicada a Investimentos em Infraestrutura Hidroviária Brasileira Utilizando Opções Reais*. PhD Thesis, Universidade de Brasília UnB, Brasília.

CEDE - Centro de Estudos e Debates Estratégicos, 2016. *Arco Norte: Um Desafio Logístico. 2016.* 392 p.

CNT - Confederação Nacional dos Transportes. *Plano CNT de transporte e logística, 2018.Conheça a lista dos projetos já concluídos e os programados para 2018*. Avançar Parcerias. 24 abril 2018. [online]http://www.avancarparcerias. gov.br/conheca-a-lista-dos-projetos-ja-concluidos-e-os-estao-programadospara-2018. Accessed May 10, 2018.

COPELAND, T; ANTIKAROV, V., 2002. *Opções Reais: Um Novo Paradigma para Reinventar a Avaliação de Investimentos*. Rio de Janeiro: Campus.

DAMODARAN, A. 2006. *Avaliação de Investimentos: Ferramentas e Técnicas para a Determinação do Valor de Qualquer Ativo*. Rio de Janeiro: Qualitymark.

DIXIT, A. K. & PINDYCK, R. S. 1994. *Investment under Uncertainty.* New Jersey, Princeton: University Press.

DIWAN, J. R., 2004. *Análise de Alternativas de Investimento na Área Petrolífera sob a Ótica das Opções Reais Embutindo a Opção do Investimento em Informação.*Master's dissertation [Master's in Production

Engineering], Pontifícia Universidade Católica do Rio de Janeiro, Rio de Janeiro, RJ.

DNIT - Departamento Nacional de Infraestrutura do Transporte 2015. *Anteprojeto de Derrocamento Hidrovia de Tocantins*.

DNIT – Departamento Nacional de Infraestrutura do Transporte 2019. *O Derrocamento do Pedral do Lourenço e seu Impacto na Logística Intermodal de Transporte via Hidrovia do Tocantins – Araguaia TO.*

FRISCHTAK, C., & MOURÃO, J., 2018. *O Estoque de Capital de Infraestrutura no Brasil: Uma abordagem setorial in Desafios da Nação*. Brasília: IPEA.

HENRY, C. 1974. *Option Values in the Economics of Irreplaceable*. Review of Economics Studies, 41, 89-104.

HULL, J. C. 2016. *Opções, futuros e outros derivativos*. Bookman Editora.

LUEHRMAN, T.A. 1998. Investment opportunities as real options: getting started on the numbers. *Harvard Business Review*, 72 3, 51-67.

MAPA - Ministério da Agricultura, Pecuária e Abastecimento, 2013. *Projeções do Agronegócio: Brasil 2012/2013 a 2022/2023 / Ministério da Agricultura, Pecuária e Abastecimento.*Assessoria de Gestão Estratégica. – Brasília: Mapa/ACS.

MACEDO, M. A. D. S., & NARDELLI, P. M. 2008. *Utilizando opções reais na análise de viabilidade de Projetos de investimento agropecuários: um ensaio teórico* No. 1349-2016-107285.

MT – Ministério dos Transportes 2009. *PNLT – Plano Nacional de Logística e Transportes*. MT, Brasília.

MT – Ministério dos Transportes 2013. *PHE – Plano Hidroviário Estratégico*. MT, Brasília. [online]<https://www.infraestrutura.gov.br/images/TRANSPORTE_HIDROVIARIO/PHE/ELABORACAO_AVAL_ESTRATEGIA.pdf.

MT – Ministério dos Transportes 2019. *Diretrizes da política nacional de transporte aquaviário*. MT, Brasília.

QUIGG, L., 1993. Empirical Testing of Real Options Pricing Models. *The Journal of Finance*, 482, 621-639.

RONCHI, R. D. C., MOURA, G. A. and ROCHA, C. H., 2013. *Mensuração do custo social subjacente à atual frota autônoma de caminhões da agropecuária nacional - um estudo de caso: soja, café e boi em pé. Journal of Transport Literature*, 72, 52-77.

SOUSA NETO, J. A.; BERGAMINI JÚNIOR, L. C. & OLIVEIRA, V. I. 2008. *Opções Reais: Introdução à Teoria e à Prática*. Qualitymark, Rio de Janeiro, RJ.

SOUZA, J. C. F., ROCHA, C. H., & SOUZA, J. G. M. 2018. Modelo de opções reais para avaliação de investimentos em novos portos e terminais portuários brasileiros. *Transportes*, 26, 103–115.

TRIGEORGIS, L., 2000. *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. Cambridge, MA: The MIT Press, 427 p.

VILLELA, T. M. A. 2013. *Estrutura para exploração de portos com autoridades portuárias privadas*. PhD Thesis, Universidade de Brasília. Faculdade de Tecnologia. Departamento de Engenharia Civil e Ambiental.

****