Value of flexibility in PPP contracts: an application of real options in airport construction projects

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ABSTRACT: The Colombian Government is planning to uptake massive capital expenditures in transportation systems PPPs (~28 billion dollars) as a countercyclical measure to overcome the infrastructure lag. There is great uncertainty surrounding these investments, and the recent plummeting of oil prices and the unprecedented devaluation of the peso have shown that black swan events can materialize. Therefore, it is important to develop projects from an early stage with a flexible approach so as to avoid future downside risks and take advantage of upside opportunities as they emerge. This kind of flexibility seeks to introduce in the system the ability to adapt to a wider range of future scenarios, and increase the expected value as a consequence. Bogotá's second airport will serve as a case study to portray the benefits of real options "in" PPP contracts in the Colombian context, and to illustrate how flexible design may considerably improve the attractiveness of an investment decision.

Keywords – real options, infrastructure, multi-airport systems, flexibility

1 INTRODUCTION

Development economists have considered physical infrastructure to be a precondition for industrialization and economic development [1] as it improves the long-term production and income levels of an economy [2]. Furthermore, it has been shown that infrastructure development is one of the essential components of poverty reduction [3] as it fosters the adequate conditions for progress in competitiveness and the expansion of a country's productive systems.

In Colombia, the lag in transportation infrastructure has been recognized as one of the most important constraints to economic growth and, in turn, one of the main challenges in competitiveness [4]. As a consequence, the government devised a comprehensive investment program that comprises the entirety of transportation modes available: land (road and rail), water (sea and river), and air. This 20-year plan aims to reduce the existing infrastructure gap and consolidate the national transportation network through a continuous and efficient connectivity between nodes [5]. This countercyclical policy, based on Public-Private Partnerships (PPPs), exhibits a positive social and economic cost-benefit ratio that confirms the relevance and high impact of the planned investments [6].

Colombian engineers structure this set of PPPs through the traditional, deterministic discounted cash flow approach that does not account for uncertainty. As a consequence, the fact that the country is facing a period of unprecedented incertitude caused by a bearish world economy, an over-supply in the oil market, the devaluation of the Colombian peso, and the peace process with the guerrillas, among others, is disregarded. In such a volatile environment, it is convenient to structure infrastructure projects that have the necessary flexibility to adapt to future changes throughout its life cycle. Such objective is attainable through flexible design and real options "in" projects, because this model can capture their intrinsic latent value. Real options analysis models infrastructure management processes as contingent decision making and is capable of yielding optimal solutions in light of multiple uncertainties [7]. The widespread implementation of this strategy has the potential of maximizing the value for money of PPPs.

2 FLEXIBILITY IN ENGINEERING

2.1 *Uncertainty in Engineering Projects*

Large infrastructure investments, like roads, airports, dams, and hospitals, are highly uncertain projects in terms of demand, capital costs, and even construction costs [8]. This is caused particularly by their long life cycles and its vulnerability to the macroeconomic context [9]. In this sense, engineering and construction projects are rife with uncertainty and ripe with flexibility, which is recognized by project managers and materialized as preliminary and feasibility studies, which can reveal information that may alter further investment and development decisions [10].

Like almost all managers, engineering project managers tend to be risk-averse given that they are willing to forgo some benefits to reduce uncertainty [10]. In fact, decision makers in civil engineering tend to be conservative and prefer alternatives with high reliability [7]. Uncertainty is often perceived as risk that is inherent to a project regardless of whether it is technical or market-related [11]. Nevertheless, some risks cannot be diversified or hedged as they are systematic. Therefore, successfully managing uncertainties that arise throughout the project's life cycle is critical for its success [12].

As a matter of fact, Miller and Lessard's (2000) study of 60 large ($985 million average cost and 10.7 years average duration) engineering projects concluded that project success depended largely on the amount of uncertainty in the project and how these uncertainties were managed [10]. Uncertainty management can take many forms, including: avoidance of uncertainty, shifting of impacts to third parties, creating buffers to absorb impacts, or providing flexibility to respond in different ways depending on how uncertainty resolves [12].

The focus on flexibility in system design represents a paradigm change because it presumes that the major requirements of the system are at least partially unknown and indeed unknowable in advance [13]. Actually, flexible design that enables future expansion benefits from larger variance in future demand because larger variance makes it more likely to expand facilities and gain access to additional revenue streams [11].

Flexible design is becoming the new paradigm for engineering systems planning [14]. It recognizes that risk is a synonym for volatility, and enables the system to avoid future downside circumstances and take advantage of new upside opportunities. It also implies a shift in the managerial approach towards a more proactive one: rather than react passively to what may come, it facilitates proactively the possibility of effective, timely responses to eventualities [15]. In general, flexible designs include features that enable the system to respond to a range of possible scenarios, either under predefined protocols or through the direction of managers.

The rationale for incorporating flexibility in infrastructure projects is rather simple, unlike the empirical application, which can be extremely complex. [16].

2.2 *Traditional Forecasting*

Most infrastructure projects have the common characteristics of large scale capital expenditures, long operation and maintenance phases for investment recovery, and multi-dimensional risks [17]. Amongst these risks, those related to the pretension of forecasting future conditions embody the highest volatility due to the indisputable fact that trends change, surprises occur, and black swan events can materialize. Regardless of the effort devoted in the task of developing a projection model that leads to very precise predictions or specifications, it is important to recognize that forecasts are 'always wrong' and that the future is inevitably uncertain [15]. A good example of this premise is the graphical comparison of the forecasted prices of oil barrels estimated by the US Department of Energy vs the actual prices. As Figure 1 illustrates, the particular conditions by which a prediction is structured determine the trend that the extrapolation will follow.

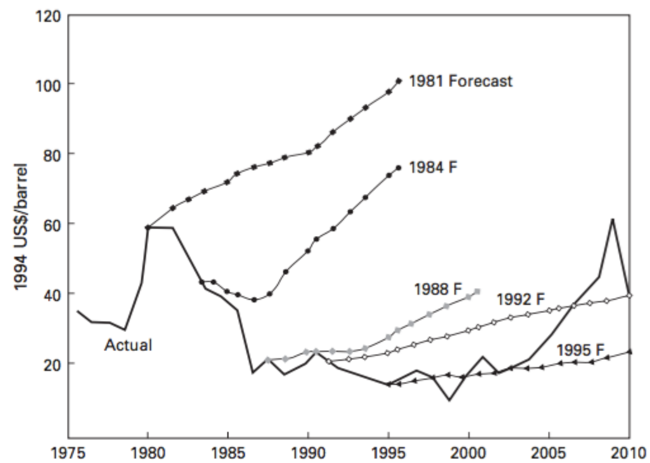

Figure 1 - Actual vs forecasted oil prices US Department of Energy [15].

In this sense, the point forecasts favored by the standard practice are inconvenient as they are demonstrably unreliable. All forecasting is based on some extrapolation of past trends into the future, and past trends are constantly changing for economic, technological, industrial, and political reasons [18]. Therefore, it is more propitious to develop a realistic assessment of both the range of uncertainties around the forecasts and the possible asymmetry in their distribution, and estimate, as far as possible, the probabilities associated with possible outcomes [15]. In addition, an added value in investment timing emerges from waiting for better information about the project and its uncertainties to present itself [19].

2.3 *Financial Options*

Derivatives (options, bonds, swaps, futures, and forwards in their plain vanilla and exotic forms) are financial instruments used to manage risk and hedge exposure [20]. A financial option gives its owner the right, but not the obligation, to buy (call) or sell (put) an asset, subject to certain conditions within a specified period of time [21] [22]. The attractiveness of options relies on the hedging of risk, where there is a limited downside but an unlimited upside [23].

The purchase price of the option is called the premium. It represents the compensation the purchaser must pay for the right to exercise the option only when considered desirable [24]. Additionally, a distinction can be plotted between American options and European options, where the former is one that can be exercised at any time up to the date the option expires, whilst the latter is one that can be exercised only on a specified future date.

The mathematical expression for the analytical value of an option and its dynamics over continuous-time models was deduced by Black and Scholes, and Merton and is used ubiquitously in financial markets [25]. They established the value of an option by constructing a portfolio of traded securities, known as a tracking portfolio, which has the same payoffs as the option. [15]. Cox, Ross and Rubinstein did the same for discrete- time models [12]. The following expression values a European call option with no dividends under the Black Scholes formulation:

$$C = S_0\phi(d_1) - Ke^{-rT}\phi(d_2) \qquad \textbf{Eq. 1}$$

Where:

S_0: Value of the underlying asset at $t=0$

ϕd: Cumulative normal distribution function

K: Strike price of the option

σ: Volatility of the relative price change of the underlying asset price

r: Risk-free interest rate

T: Time to expiration date

The equation rests upon the following assumptions that are relevant for real options analysis, among others: the price of the underlying asset follows a particular form of geometric Brownian motion referred to as random walk, there are no arbitrage opportunities, interests rates are constant and known, volatility is constant, and ϕd are risk neutral probabilities [26].

2.4 *Real Options*

The term real options was coined by Myers [27] in 1977, who argued that the value of a firm includes the real assets in place plus the present value of options to make further investments in the future [28].

Unlike financial options, which deal with financial assets and derivatives, real options regard physical structures or systems [29]. Nevertheless, the option maintains its purpose: it gives its buyer the right but not the obligation to delay expensive or irreversible decisions. Real options differ from financial options in that the underlying assets are real assets that are often not traded and represent, for example, contingent decisions to delay, abandon, expand, contract or switch project components or methods [12]. Moreover, real option analysis takes the impact of uncertainty on future decisions into account, considering the value of the opportunities that risks create [30]. These decisions require a shift in the managerial mindset so as to recognize the situations in which it is convenient to execute an option, in order to either minimize the damage from or take advantage of the uncertain future [29].

The flexibility to postpone an investment in order to gain more information about the uncertain variable is only valuable under uncertainty. [25] Additionally, a flexible design might include extra features that enable it to adapt to different situations that may increase the Capex and will be penalized by the deterministic valuation that only visualizes a unique outlook. Hence, a probabilistic approach will fathom the value that the options represent in the life cycle of the project.

Infrastructure investments are similar to exercising a call option on a share of stock [9]. Table 1 presents a simple analogy of how the variables that comprise financial options relate to real options.

Table 1 Analogy between the variables of financial options and real options [31]

Financial options	Real options
Time to maturity	Time until the investment opportunity disappears
Exercise price	Costs of irreversible follow-on investment
Volatility of stock return	Variability of growth in project value
Share price	Present value of expected CFs
Risk-free rate of return	Risk-free rate of return
Dividend	

A change in any of the variables will alter the value of the option in the respective investment (e.g., a higher expenditure lowers the option value; greater uncertainty increases the volatility rate, which leads to potential higher values achievable, which in turn leads to increased option value) [32]. As a consequence, mapping an investment opportunity as a call option helps managers to understand the role played by uncertainty when it comes to decision making, as well as recognizing the asymmetry in the options net payoff [33].

In order for real options analysis to be feasible, a critical issue is to understand and capture precisely the value of this flexibility. Achieving this with traditional financial tools, such as net present value (NPV) and discounted cash flow (DCF), is difficult because the value of the option becomes a recurrence problem [28]. NPV and DCF cannot keep track of those interdependencies and in consequence do not allow capturing the inherent value of flexibility [34].

2.5 *Discounted Cash Flows*

DCF analysis is the generally preferred method for establishing the value of an asset not set in an active market [35]. Nevertheless, it has significant limitations in dealing with uncertainty and flexibility [15] as the risk of subsequent cash flows can change as development proceeds or new information is received [36].

DCF is a fundamental valuation methodology broadly used by finance professionals and is premised on the principle that the value of a company, business, or asset can be derived from the present value of its projected free cash flow [37]. Correspondingly, the most fundamental assumption behind a DCF analysis is that it is possible to project the stream of net cash flow, income minus expenses, with a degree of confidence over the lifetime of a project or system [15]. Said extrapolated cash flow rests on a pro-forma financial statement modeling exercise that is based on a series of deterministic hypotheses regarding the periodic variation of assets, liabilities, and equity [38]. These premises are a bold over-simplification of reality as the value of the cash flows is highly sensitive to small changes in some input values (e.g., interest rate). Therefore, it must be recognized that DCF valuation estimates are almost always going to be imprecise by virtue of development opportunities and future growth rates that are especially hard to settle [24].

Additional problems regarding the DCF method are the fact that expected future cash flows do not adequately reflect the flexibility within the investment and the operation of the assets; and that the cash flows at different points in time usually require different discount rates to reflect their risk appropriately. Furthermore, DCF techniques favor short-term projects in certain markets over long-term and relatively uncertain projects [31]

As a consequence of the above mentioned, some of the answers generated through the use of the traditional discounted cash flow model are flawed because the model assumes a static, one-time decision-making process. Whereas the real options approach takes into consideration the strategic managerial options certain projects create under uncertainty and management's flexibility in exercising or abandoning these options at different points in time, when the level of uncertainty has decreased or has become known over time. [23]

The identification of the best opportunities for flexibility requires the implementation of new measures of value. Just as real options are situated between standard engineering practice and finance, so must the metrics be [13]. As a consequence, de Neufville (2008) introduced the concept of expected net present value (ENPV) over a distribution, rather than a fixed, single NPV result [15].

Another useful instrument derived from financial engineering is the value at risk and gain diagram (VaRG), a convenient way to display the distribution of possible results. [13] It builds upon the value-at-risk (VaR) concept used by bankers to identify the risk of the expected in a given time horizon and with a defined occurrence probability [39]. Many metrics can be read from a VaRG curve, including the ENPV, the maximum and minimum values, and the volatility of the return (see Figure 2) [13].

A project´s risk exposure can be hedged at the design phase by shifting the VaRG curves to the right as much as possible, resulting in a higher ENPV. It is also convenient to reduce the down side tail (in the form of put options), and increasing the upside tail (as call options) [13].

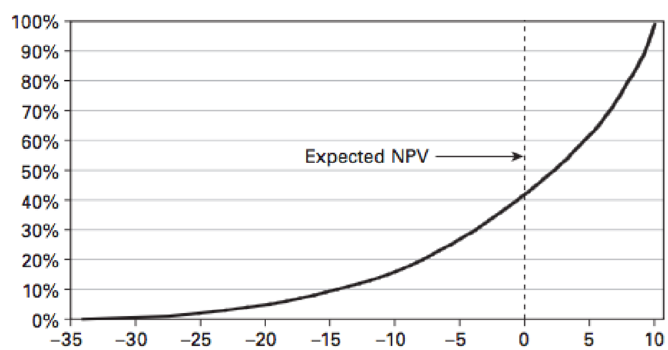

Figure 2 Illustrative VaRG curve [15].

2.6 *"On" Vs "In"*

Real options can be categorized as those that are either "on" or "in" projects [40]. Real options *"on"* projects are financial options taken on technical elements, treating technology itself as a 'black box', whilst real options *"in"* projects are options created by changing the actual design of the technical system [41].

Real options "on" projects are mostly concerned with the valuation of investment opportunities throughout the operative phase, do not require knowledge on technological issues, and interdependency/path-dependency is not frequently an issue [41]. A close parallel can be drawn in relation to financial options, as Table 2 presents.

Table 2 Parallel between real options on projects and financial options [42]

Real Option on a project	Financial option
Deferral option to postpone a project	American call on project's value
Abandonment option to sell or stop a project	American put on project's value
Expansion option to increase the size of a project	American call on the value of additional capacity installed
Contraction option to reduce the size of a project	American put on the value of additional capacity installed
Options to extend the life of an asset	European call on the asset's future value

On the other hand, real options "in" projects require a deeper understanding about the way the system operates and its specificities [41]. Said requirement derives from the fact that they result from a conscious decision implemented in the system's design. Nevertheless, such knowledge is not readily available among options analysts, who are generally versed in financial engineering. Consequently, there have so far been a reduced number of analyses of real options "in" projects, despite the important opportunities available in this field [43].

A system with the ability to deal with a varied number of uncertain conditions will unmistakably include some features that the contrary will not. Nevertheless, the extra construction cost can be viewed as the premium that will allow for the option to be exercised later [41]. As a consequence, the value of the flexibility embedded in the system or the real option "in" the project will result from the difference between the cost of capital for the execution of the project with and without flexible options (See Eq. 2).

$$Option\ value = NPV_{Flexible\ setup} - NPV_{Inflexible\ setup} \qquad \textbf{Eq. 2}$$

It is vital to understand that real options analysis is not just a simple set of equations or models. It is an entire decision-making process that enhances the traditional decision analysis approaches [23]. As it has been mentioned, it requires a shift in the managerial attitude towards a more proactive approach and is part of a complete learning model.

2.7 *Real Options Valuation Models*

2.7.1 *Black-Scholes Option Pricing Model*

The Black-Scholes option pricing model (OPM) is the most well-known solution to the option pricing problem as it applies to those European call and put options that do not pay dividends [44]. However, this relatively simple method is not always able to provide project managers with the answer of option values [45].

The assumption of a unique, fixed decision date does not hold in infrastructure development, whose dynamics resemble more the American type of options. Furthermore, underlying assumption such as volatility, price, duration, risk-neutrality, well-behaved future asset values, complete markets for assets, the independence of option holders from the future performance of the underlying asset, and no arbitrage conditions limit the use of the approach [10] [12]. Thus, it is very difficult to apply this approach to large-scale complex engineering projects targeted in this thesis [45].

2.7.2 *Binomial Lattice Model*

Another widely used method for pricing options is the Binomial Lattice Model developed by Cox, Ross and Rubistein (1979) [46], a more simplified discrete-time approach to valuation of options compared to the Black-Scholes OPM [36]. It is referred to as a binomial model because it assumes that, during the next time period, the price of the underlying asset will go to one of only two possible values [44]. The recombinant characteristic of the binomial lattice tree reduces the possible outcomes for N periods to expiration date from 2^N to $N+1$.

This approach can illustrate the intermediate decision-making processes between $t=0$ and the exercise of the option (early exercise of an American option) [42]. Furthermore, this method is very effective if only one uncertainty is being modeled, but difficult to conduct if there are several simultaneous uncertainties [45].

2.7.3 *Monte Carlo Simulations*

Monte-Carlo Simulations (MCS) are an analytical method that generates the statistical distribution of possible outcomes corresponding to probability-distributed sampled inputs [45]. It is a powerful tool to efficiently generate thousands of futures, run all these futures simultaneously through a model of system performance, and summarize the distribution of possible performance consequences graphically [15].

3 MULTI-AIRPORT SYSTEMS

In addition to the resilient growing demand for air transportation around the world [47], the explicit difficulties to update key air transportation infrastructure of national governments portends a scenario where demand will exceed capacity. It appears that the development of multi-airport systems is a key mechanism by which air transportation systems will be able to meet future demand worldwide [48].

A multi-airport system is a set of significant airports that serve commercial transport in a metropolitan region, without regard to ownership or political control of the individual airports that comprise it. Multi-airport systems have been a feature of all metropolitan areas with the most originating and terminating traffic, without exception and over several decades. As of 2012, the minimum level was about 15 million annual originating passengers for the entire metropolitan area [18].

According to de Neufville, et. al. (2013), airport planners and operators dealing with multi-airport systems have to deal with uncertain, unstable situations due to the fact that the volatility in the level of traffic and the nature of their customers may make the facilities at secondary airports obsolete or unnecessary. As a consequence, airport planners should carefully assess the risks and invest in flexible facilities that give them appropriate options on future developments.

Additionally, a civil aviation authority with the intention of creating a multi-airport system has to anticipate that traffic at secondary airports is typically much more volatile than at primary airports. This phenomenon is rooted in the fact that competition between airports in a multi-airport system inevitably leads to a concentration of traffic at the primary airport [18]. Governments might intervene the national air transportation system to allocate a considerable portion of traffic to the secondary airport, however the general rule is that market dynamics ultimately prevail and this efforts are impractical [18].

The uncertainty embedded in multi-airport systems fosters the adequate conditions for the implementation of flexible designs and real options. In this regard, flexible facilities will enhance the airport operators' ability to respond to changing market patterns and enable them to cater to the range of services airport users desire [18]. Therefore, airport planners and operators should develop secondary airports flexibly and incrementally, so that they can postpone, and even avoid, unnecessary Capex and Opex.

Moreover, incremental development creates an option for the airport operator to design each addition according to the changing market requirements. Nevertheless, airport operators should configure their facilities so that they can accommodate different types of traffic and change easily to meet different needs [18]. What these developments may lack in architectural splendor, they make up for functionality and resilience.

4 PUBLIC PRIVATE PARTNERSHIPS

4.1 *Overview*

Even though there is no internationally accepted definition of Public-Private Partnerships and different jurisdictions use varied nomenclatures to describe similar projects, transversal elements exist among PPP interpretations. The InterAmerican Development Bank defines a PPP as a long-term contract between a private party and a government entity, for providing a public asset or service, in which the private party bears significant risk and management responsibility, and remuneration is linked to performance [49].

The characteristic duration of PPP arrangements implies that many components and risks can arise from such a long-term contractual relationship and change dynamically over the PPP's life-cycle [50]. Due to the fact that a pillar of PPPs is optimal risk sharing that leads to higher benefits for both parties, it is clear that real options can bolster the benefits rendered to society and the value for money of the contract. Nonetheless, the widespread approach to this situation promotes practices that focus project management on limiting negative exposure to uncertainty rather than on capturing upside potential and thereby limits the potential benefits of real options used to hedge risk exposure [12].

4.2 *Colombian Case*

Recent PPPs in Colombia have been structured as Build-Operate-Transfer (BOT) projects, also known as Design-Build-Finance-Operate (DBFO) arrangements. According to Garvin (2004), this project delivery method features a high integration of life-cycle activities, facility innovation, a financing cost competition, and government commitment amongst others. These characteristics are compatible with the real options framework.

Frequently, BOT projects possess managerial options which are not directly valued by either governments or private consortiums. Without a careful appraisal of the opportunities and risks inherent in such arrangements, development may not occur at all if the project itself is undervalued because managerial flexibility is ignored, or the concession agreement struck between the government and the private developer may include disproportionate subsidies since financial guarantees are given for free [51].

As a consequence, private participation in a BOT delivery strategy, however, is conditioned upon the mitigation of the risks that may adversely impact a project's profitability [52]. A relevant BOT project risk that may seriously undermine a project's profitability is the revenue risk, that is, “the risk that the project may not earn sufficient revenue to service its operating costs and debt and leave an adequate return for investors” [53] [51].

The Colombian government has included in the most strategic and risky PPPs minimum revenue guarantees in order to improve their creditworthiness and make them bankable. In effect, the government has granted the sponsor a contract to cover the revenue shortfall over a specific operating period (this type of scheme is akin to a financial put option) [52]. Clearly, this “real” option has value. If the value of such an option is substantial and no effort is made to quantify it, then the government may unknowingly provide the sponsor a tremendous subsidy.

In fact, many projects are multi-million dollar, multi-year enterprises where the opportunity to ‘get it right’ is limited, and little or big mistakes may not necessarily be absorbable for either the project manager or organization. These features and characteristics of the construction industry make it fertile ground for the use of real options [12].

5 CASE STUDY

The construction of the second airport for Bogotá aims to configure a multi-airport system for Colombia’s capital district that can manage the increasing traffic demand. El Dorado II (ED-II) airport will be constructed 20 miles from El Dorado and will feature 3 parallel runways that will be able to operate simultaneously with the existing ones, according to official sources.

This research work intends to evaluate the introduction of flexibility in the PPP contract that features a phased investment option in the construction of the airport (air side + land side). The purpose of this research is to model and quantify the economic benefits of incorporating real options in the flexible, modular, and staged construction of the ED-II airport as a low cost terminal for national flights. In this paper, the BOT arrangement will be structured as a PPP with an operation and maintenance phase of 25 years, starting in 2021. Furthermore, ED-II will receive the short-haul, non-hub, low-cost national traffic that currently operates in El Dorado. In order to attract low cost carriers (LCCs), a differentiation factor will be included regarding lower aeronautical charges, by charging 90% El Dorado’s fees [54].

As some of the inputs had to be estimated, this research is expected to be regarded as a motivation for the use and incorporation of real options and flexibility in design, rather than a complete and accurate study for the development of the ED-II airport.

5.1 *Sources of Uncertainty*

In the current climate, long-term forecasts cannot be developed with any degree of confidence. On the contrary, as has been extensively documented, forecasts of airport traffic today are “always wrong” [55]. Therefore, it is important to recognize the major sources of uncertainty over the life cycle of the project so as to include possible real option in the system that will allow the management to exploit possible upside opportunities and minimize downside scenarios. It is also expedient that the ranges of circumstances and their probabilities are determined, in order to appreciate the context in which the system will function [15].

The two most decisive economic variables that influence the dynamics of aviation in Colombia are the COP/USD exchange rate and oil prices. In the last five years, the exchange rate between Colombian pesos and United States dollars has doubled [56] while the crude oil Brent lost a maximum of 79.7% of its price [57], as the following figures depict.

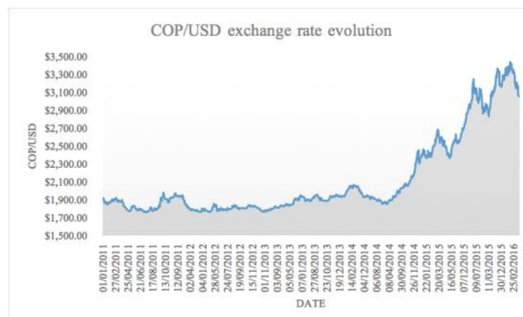

Figure 3 COP/USD Exchange rate 2011-2016

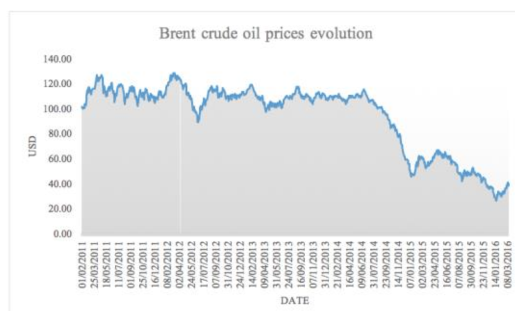

Figure 4 Crude Oil Brent price quotes 2011-2016

Other variables that may disrupt the air transportation system and that need to be taken into account when designing an airport are:

- *Security threats and terrorism*
- *Health threats: zika, chikungunya, dengue*

- *Tourism reduction*
- *Airline alliances*
- *Increased competition*
  - *Airports*
  - *Airlines*
  - *Multi airport systems*
  - *Alternative modes of transportation*
- *Airport operations*
  - *Hub and spoke*
  - *Point to point*
- *Economic deregulation: rise of LCCs*
- *Political deregulation: surge of open skies agreements*
- *Technical innovation*
  - *Aircrafts*
  - *Satellite-based navigation aids: GNSS*
  - *Systems within the terminals*
    - *Automated people movers*
    - *Auto check in counters*

Moreover, it is necessary to consider the existence of cases where political commitments trump technical feasibilities, resulting in the construction of unnecessary facilities to attend an adequately served traffic.

As stated by Yescombe (2002), the most relevant risk to whom these type of projects are more sensible under standard conditions is the revenue risk, caused by fluctuations in demand. As a consequence, this parameter will be the center of the models of this research project.

5.2 *Geometric Brownian Motion*

The evolution of demand was modeled as a random walk Geometric Brownian Motion, which is a special case of the Brownian Motion Process, described by the following stochastic differential equation:

$$dS_t = \upsilon S_t dt + \sigma S_t dW_t \qquad \textbf{Eq. 3}$$

Where:

S_t: Value of the underlying asset at t.

W_t: Wiener process with mean equal to 0 and variance equal to 1 [58].

υ: Average annual growth rate of traffic demand.

σ: Volatility (standard deviation) of the growth rate of traffic.

5.3 *Scenarios*

Four scenarios will be assessed with different assumptions regarding the uncertainty (probability distributions) and strategies to confront such uncertainty (real options and flexibility). All the scenarios will incorporate land banking [18] through American call option contracts that give the right but not the obligation of purchasing the terrain. On the other hand, a zoning agreement will be a premise so as to avoid any artificial capacity constraints caused by incompatible real estate development.

5.3.1 *Inflexible Deterministic Scenario*

An inflexible deterministic scenario (IDS) will be modeled where the demand will evolve exponentially as an extrapolation of the average annual growth rate. Furthermore, two runways of 3840 meters of length will be constructed before the inauguration at 2021, and a call option will be available for terrain of the third runway. A terminal able to handle 12 million passengers per year will be built as well. Said terminal will be dimensioned to provide an IATA *Adequate* Level of Service (LOS) [59]. The land side will be able to accommodate 110% of its nominal capacity before collapsing whilst the air side 120%.

5.3.2 *Inflexible Stochastic Scenario*

The inflexible stochastic scenario (ISS) will model demand as a random walk process that follows binomial and normal distributions. The remaining assumptions of the IDS hold for the ISS.

5.3.3 *Flexible Deterministic Scenario*

The flexible deterministic scenario (FDS) will use the same assumptions of the IDS model for demand evolution. Moreover, the airport's operation and maintenance (O&M) phase will start with a single runway of 2800 meters with an expansion option to 3840 meters. Two American call options will be executable for the land extension of the remaining runways. Regarding the land side, an initial module for 6 million passengers per year will be built initially with the option of modular expansions of 3 million passengers per year. These modules will offer an area per occupant equivalent to IATA *Good* LOS [59]. In these cases, both the land and air sides will be able to accommodate 120% of their nominal capacity before collapsing. Once the nominal capacity at any given period of time is realized, the management will set in motion an expansion plan for a new module that will be operationalized in the year when the actual capacity of the existing modules is met.

5.3.4 *Flexible Stochastic Scenario*

The flexible stochastic scenario (FSS) will model demand as a random walk process that follows binomial and normal distributions. The remaining assumptions of the FDS hold for the FSS.

5.4 *Construction of the Model*

The model is designed to analyze the effect of demand for an O&M phase of 25 years. A discount rate of 12% will be used to account for the time value of money, and an exchange rate of 3000 COP/USD was assumed. Operational revenue is based on Colombia's Civil Aviation Authority *Resolution 00310* for an aircraft mix that resembles the LCCs that currently operate in El Dorado. The number of movements per period is calculated according to the average capacity of said mix and 50% of total movements are take-offs. The air side and land side facilities' Capex and Opex are calculated based on their specifications and typical construction index values for the airport industry.

The model is formulated to allow the user to select the inaugural period of the facilities that have been described, as well as to emit alerts regarding possible revenue spillage.

5.4.1 *Cash Flow Pro-Forma*

This research will employ a simplified cash flow that disregards asset depreciation and taxes, based on operational revenue, capital expenditures, and operational expenditures. Revenues will be calculated as the aeronautical charge multiplied by the minimum between traffic demand and capacity for any period. The following equation summarizes the cash flow used:

$$CF_i = \min\{TD_i, Cap_i\} \cdot F_i - Capex_i - Opex_i \qquad \textbf{Eq. 4}$$

Where:
CF_i: Cash flow at $t=i$
TD_i: Traffic demand at $t=i$
Cap_i: Capacity at $t=i$
F_i: Fare at $t=i$
$Capex_i$: Capital expenditure at $t=i$
$Opex_i$: Operational expenditure at $t=i$

This cash flow rests upon the additional premises: Capex is cashed one period before the operationalization of the assets, and a dual till principle is followed where only aeronautical activities are considered to cover expenditures [60].

5.4.2 *Binomial Lattice Model*

Binomial lattice models are the simplest form of the Brownian Motion processes (Eq. 3) [15] where the initial variable X can take only two values at the end of one time period: *u*X or *d*X. *U* (for up) and *d* (for down) are positive constants that allow the construction of a recombinant discrete lattice of the uncertainty, which represents its evolution over time [7].

The following equations were used to formulate the model [24] [29] [46] [61]:

$$v = \frac{1}{\Delta t} \cdot \sum_{t=1}^{N-1} \ln\frac{\mu(t+\Delta t)}{\mu(t)} \Big/ (N-1) \qquad \textbf{Eq. 5}$$

$$\sigma = \sqrt{\frac{1}{\Delta t} \cdot \sum_{t=1}^{N-1} \left(\ln\frac{\mu(t+\Delta t)}{\mu(t)}\right)^2 \Big/ (N-2)} \qquad \textbf{Eq. 6}$$

$$u = e^{\sigma\sqrt{\Delta t}} \qquad \textbf{Eq. 7}$$

$$d = e^{-\sigma\sqrt{\Delta t}} = \frac{1}{u} \qquad \textbf{Eq. 8}$$

$$p = 1/2\left(1 + \frac{v}{\sigma}\sqrt{\Delta t}\right) \qquad \textbf{Eq. 9}$$

Where:
μ: Traffic demand
Δt: Time step
N: Number of traffic data
u: Upward multiplier
d: Downward multiplier
p: Increase probability
$1-p$: Decrease probability

The values of v and σ were calculated based on the multiannual traffic information (2000-2015) available in the El Dorado's master plan [62] according to Eq. 5 and Eq. 6, and are summarized with the other parameters calculated for the model in Table 3. A small BLM was created to estimate the expected number of passengers for the year 2021, which will serve as the initial node for the BLM.

Table 3 Calculated parameters for the BLM

Parameter	Value
ν	7.88%
σ	10.53%
u	1.11
d	0.90
p	0.87
1 - p	0.13

Based on the presented formulas, eight binomial lattices were formulated in order to estimate the ENPV of ED-II and assess the impact of the investment decisions' timing in the value of the asset. The first three were used to calculate the expected number of passengers per node. The fourth, fifth, and sixth evaluate the expected and realized traffic, given capacity constraints due to the construction of runways and modular terminal buildings. The seventh binomial tree computes the Cash Flow for each node and eighth estimates the ENPV.

The ENPV of the project can be calculated by a backward induction process developed by Ishii (2007), which can be mathematically summarized by a recurring formula. Eq. 10 provides the formulation of the net present value (at $t=i$) of the cash flow stream descending from the node (i, *j*). The repeated used of this equation from the final period to the first period allows the calculation of the total net present value of the project.

Eq. 10

$$NPV_i(CFS_{i,j}) = CF_{i,j} + \frac{p \cdot NPV_{(i+1)}(CFS_{i+1,j})}{1+r} + \frac{(1-p) \cdot NPV_{i+1}(CFS_{i+1,j+1})}{1+r}$$

Where:
$CF_{i,j}$: Cash flow at the node (*i,j*)
$CFS_{i,j}$: Cash flow stream that descend from node *(i,j)*
$NPV_i(CFS_{i,j})$: Net present value of the cash flow stream $CFS_{i,j}$ at time *i*
r: discount rate

5.4.3 *Monte Carlo Simulation*

The analytical solution of the random walk model that will be implemented in the MCS is given by Eq. 11 [58]:

$$S_t = S_{t-1} e^{\left(\left(\nu - \frac{1}{2}\sigma^2\right)t + \sigma W_t\right)} \qquad \textbf{Eq. 11}$$

In the previous equation, the term $(\nu - 1/2\,\sigma^2)t$ controls the trend of the trajectory whilst the term σW_t controls its random noise effect. In the following figure (Figure 5) both effects are depicted, where the trend is represented by the dotted line while the effect of the random walk is represented by ten iterations of the model.

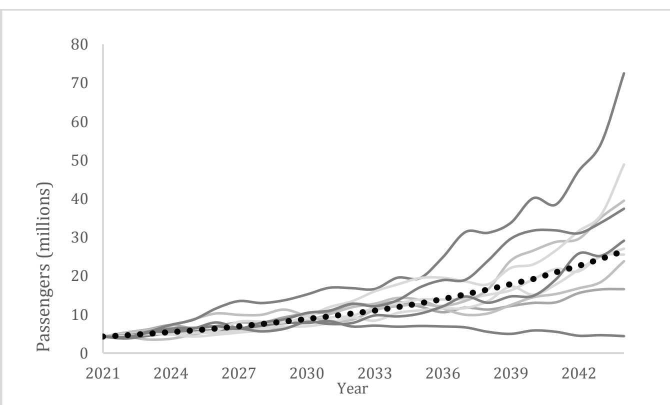

Figure 5 Dynamic traffic forecast

The Pro-Forma for the MCS evaluates the need for facility expansion for the airside and landside by imposing restrictions upon the demand that can be served. As a consequence, the construction of a new runway or an additional module must be considered. In addition, it adjusts the Capex and Opex accordingly.

According to the convergence of mean values and standard deviation (Figure 6), the results of the model stabilized within approximately 250 iterations. Nevertheless, 500 simulations were run given the short time of execution implied.

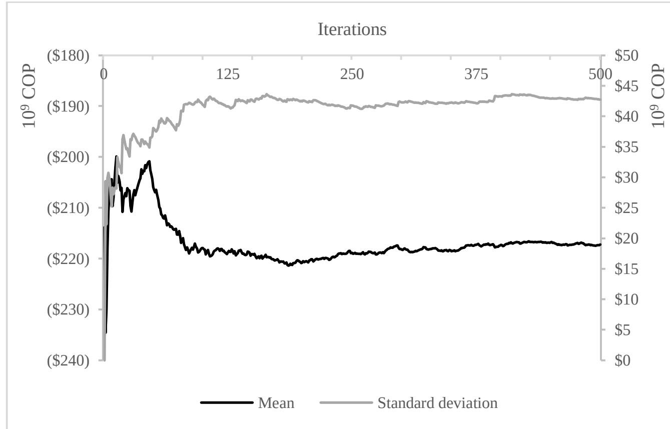

Figure 6 ENPV mean and standard deviation convergence

5.5 *Results*

Following the decision rules upon which the model relies, the following tables present the periods in which new assets are operationalized and its effect in air and land side capacity.

Table 3 Operationalization period for air side facilities

Asset	Period	Year	Air side capacity
Runway 1	1	2021	90,000
Runway 2	12	2032	180,000
Runway 3	21	2041	270,000

Table 4 Operationalization period for land side facilities

Asset	Period	Year	Land side capacity
Module 1	1	2021	6,000,000
Module 2	9	2029	9,000,000
Module 3	14	2034	12,000,000
Module 4	18	2038	15,000,000
Module 5	21	2041	18,000,000
Module 6	23	2043	21,000,000

The analyzed scenarios expose El Dorado II airport as a project with considerable risks. Table 5 summarizes the results obtained after running each scenario. As was expected, the introduction of real options has positive effects in the value of ED-II. Particularly, the inflexible MCS renders a negative ENPV of COP 344,648 million while the flexible one COP -92,279 million. The corresponding standard deviations are similar, which is consistent with the distribution used for the random walks. Regarding the flexible scenarios, the deterministic, fixed-rate setting offers the highest NPV, followed by the BLM's and the MCS's ENPVs. Such result may be presented as an argument for the convenience of traditional forecasting, but it does not recognize of uncertainty nor quantify its effects. Therefore, it is not an adequate metric.

Table 5 Expected net present value (ENPV) for the development of ED-II Airport in million COP

Scenario	NPV-ENPV	Std. Deviation
IDS	$ - 368,504	
ISS-BLM	$ - 397,787	
ISS-MCS	$ - 344,648	$ 92,889
FDS	$ - 72,003	
FSS-BLM	$ - 86,730	
FSS-MCS	$ - 92,279	$ 89,519

The results obtained allow for the option's value calculation, conforming to Eq. 2. For the BLM, the real options have a value of COP 311,057 million while for the MCS, the value is equal to COP 252,369. These values are consistent with the proposition that a premium must be paid in order to be able to exercise a determined option, and offer a considerable reduction in the prospective downside of the project.

The VaRG curves (Figure 7) are consistent with the results and offer additional and interesting information. The FSS out performs the ISS in every possible outcome, which is explained by the positive shift of the curve. Furthermore, although the modelled mean values are negative, the FSS exposes an upside opportunity of value generation for the project. Such opportunity is disregarded in the deterministic analysis and inexistent in the inflexible scenarios.

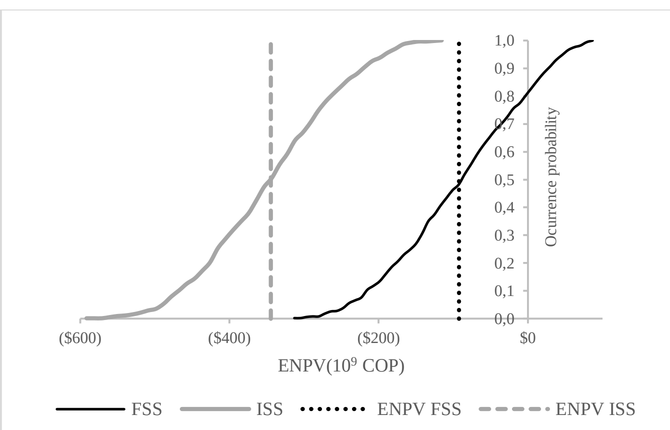

Figure 7 Value at Risk and Gain (VaRG) curves for the FSS and ISS

The fact that the resulting ENPVs are negative has three possible explanations: an overestimation of the opportunity cost represented in the discount rate, an inadequate extrapolation of operational revenues, or the analysis of a project where revenues do not cover expenditures and should not be executed. The first two hypotheses will be tested in the following sensitivity analyses.

5.6 *Sensitivity Analysis*

The discount rate will be modeled as a binomial variable with range between 4.00% and 16.00% in order to evaluate the project from the perspective of private and public stakeholders, as their cost of opportunity often diverges. 500 simulations of the FSS-MCS resulted in an ENPV of COP -39,132 million with a standard deviation of COP 84,347 million. Such improvement in the outcome of the project is substantiated in the premise that at lower discount rates, higher net present values do to the time value of money. Nevertheless, regardless of the values modeled, the discount rate selection is a function of the investor's risk aversion.

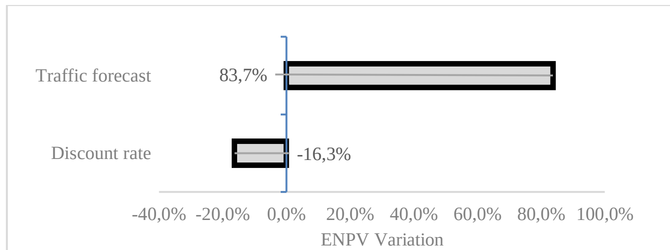

Figure 8 Sensitivity analysis tornado chart

From Figure 8 it is clear that the model is most sensitive to variations in traffic forecasts, rather than to the discount rate. Therefore, it is important concentrate on the effects of uncertainty in this variable. Close scrutiny of the calculated annual growth rate of traffic demand recognizes that the estimated value based on the equations used is unusually high. This value almost duplicates the average growth rate previsions for El Dorado Airport and global aviation [47] [62]. As a consequence, it makes no sense to analyze a bullish set-up. On the other hand, a bearish state will undoubtedly reduce the operational revenues and unbalance the assumptions of the initial scenarios. With an estimated annual rate of 4.14%, the model indicates that there is no need to build more than one runway, and only one additional module is needed at $t=20$ for a total of 9 million passengers. Also, an ENPV of COP -136,896 million with a standard deviation of $54,985 million is calculated.

6 CONCLUSIONS AND FURTHER WORK

Flexibility in transportation systems has value, as it allows a better response to the unveiling of uncertain conditions. In the case of a proposed MAS for Bogotá, the flexible, modular, and staged construction of El Dorado II airport is highly beneficial for the project. Nevertheless, the fact that the ENPV is negative in even in the most favorable circumstances, may indicate that the project is not feasible and it is being promoted for political reasons. Accordingly, financial and technical efforts should be focused on increasing the technological capacity of air traffic management services in El Dorado Airport and acquiring the land for the construction of a new runway.

6.1 *Colombian PPP Framework and Real Options*

A governmental strategic project with a negative net present value implies, under the Colombian PPP framework, a sovereign guarantee that secures a minimum amount of user fee revenue to the concessionaire. This action has the intention of improving the creditworthiness of the project's financing arrangement and can be understood as a portfolio of European put options [51]. Traditional finance evaluation in Colombia does not assess this type of real options, which clearly have value.

On the other hand, the real option of expanding tolled facilities when levels of service are inadequate opens a potential upside for the concessionaire (resembling an American call) that also has contractual value [51]. Hence, financial evaluation practices must be upgraded in order to incorporate real options into financial feasibility studies and increase the bankability of projects.

Colombia, as a greenfield for real options, presents the same reasons for slow adoption as those described by Garvin and Ford (2012): a profound lack of knowledge and understanding of real options by managers, a paramount mathematical complexity in their assessment, and the fact that the quantitative real options models rely on too many assumptions. The last two arguments are not exclusive of real options. As has been stated, traditional DCF analysis is built upon an important amount of suppositions and simplifications. Nevertheless, real options recognize and incorporate uncertainty in their analysis, hence dismissing any infallibility premise.

Consequently, a paradigm shift is necessary in order to integrate flexibility in engineering systems design within the culture of governmental agencies in charge of PPP structuration. This buy-in has to be a top-down approach where the senior management drives the flexible design initiative, as a bottom-up perspective has the risk of being understood as another inapplicable business school novelty [23]. As a consequence, real options analysis would become a requirement of unsolicited proposals that can hedge the risks inherent to infrastructure projects. In order to streamline the process, further development of the real options framework and adequate heuristics is mandatory with a strong educational support.

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