# *Whether and When to Invest in Transportation Projects: Combining Scenarios and Real Options to Manage the Uncertainty of Costs and Benefits*

***Abstract* -** Transportation infrastructure projects are a cornerstone of economic growth. However, the issue of whether new transportation infrastructure projects deliver the expected benefits has come under considerable scrutiny. The growing economic uncertainty and the tightening of budget constraints have made the design, evaluation, and selection of such high-cost projects particularly critical. There are disagreements as to how project decision-makers can evaluate the long-term costs and benefits of infrastructure projects. The objective of this paper is to address such disagreements. We develop and apply an innovative methodological approach that combines real options with scenarios to help policymakers assess the costs and benefits of transportation projects. While these techniques have been widely adopted in corporations, there is little empirical evidence regarding their combined use by project decision-makers dealing with complex infrastructure projects. In this paper, we fill this gap in the planning and project studies literature. We show that scenarios and real options can be very helpful in developing a more comprehensive understanding of long-term impacts of major infrastructure projects and thus in selecting the most relevant projects. Overall, our study assists the debate on the management of the uncertainty of long-term costs and benefits of infrastructure projects and helps cope with such uncertainty.

***Managerial relevance statement*** - In this paper, we design and apply a new methodological approach aimed at helping project decision-makers cope with the uncertainty of transportation infrastructure projects by enhancing decision-makers' ability to assess long-term effects on economic development and growth. Specifically, the innovative methodological approach we illustrate in this paper is designed to allow policy-makers to develop a shared understanding of investment potential of major investment projects in transportation infrastructure, select projects that are most likely to contribute to economic growth and focus their resources on such projects while reducing the financial risks inherent in major investment projects by regarding such projects as consisting of different steps, each entailing the right but not the obligation to proceed forward to the next step. Overall, the methodological approach we propose in this paper helps governmental institutions facing tightening budget constraints optimize the use of their budgets and their overall strategy for economic growth.

***Index Terms* -** Transportation projects; Decision-making under uncertainty; Project planning; Scenario planning; Real options

# I. INTRODUCTION

Public infrastructure and construction projects are major tools for enhancing economic growth [1] [2]. However, the growing turbulence of the economy and the tightening of budget constraints have made the design, evaluation, and selection of such high-cost projects particularly critical [3] [4], thus underscoring the challenge of optimizing the use of public money by selecting the most beneficial projects for local communities and regional growth [5]. Project decision-makers have acknowledged high uncertainty and incomplete control in dealing with the long-term challenges of transportation infrastructure projects and deciding on their implementation [6] [7]. In the broadest sense, when the key characteristics of major infrastructure projects in terms of their ambition, social and organizational relations, temporality, timescale and impact [8] are considered, uncertainty can be defined as a state of not knowing or a lack of certainty [9].

Although discounted cash flow (DCF) techniques such net present value (NPV) and internal rate of return (IRR) have long been applied by practitioners for evaluating investment alternatives (e.g., [10]), these techniques have been criticized because of being inadequate and incomplete in assuring a rational decision process able to capture ‘intangible’ project attributes and the value of future flexibility (e.g., [11] [12]). In response, scholars have clearly emphasized the difficulties inherent in the ex-ante evaluation of transportation infrastructure benefits [13] [14] and developed ad hoc techniques for coping with the growing uncertainty of investment decisions. Among such techniques, scenario planning and real options have become quite popular [15][16]. Scenarios (also referred to as scenario planning hereafter in the paper) are alternative views of the future in the form of different configurations of key drivers of change. Their rationale is not to predict the future but rather to enable decision-makers to revise assumptions about the future and mental models [17]. Apart from scenarios, another key approach to uncertainty management is that of real options, which showed that corporate assets can be valued using option pricing techniques. Real options theory emphasizes the idea that many initial investments provide firms with opportunities (but not obligations) to make subsequent follow-up investments [18].

Real options are traditionally based on the same models that have been used to value financial options, that is, the Black-Scholes [19] and Merton [20] option pricing formula, and the binomial option valuation method [21] and the Monte-Carlo method [22]. Both financial options and real options use volatility, i.e., the degree of fluctuation in price of a market or security, in their treatment of uncertainty, by assuming that the volatility or risk of the underlying asset can be determined accurately and readily. However, whereas for traded financial assets this would most probably be the case, as there is likely to be sufficient historical data available to assess the underlying asset's volatility, this might not be the case for large, one-off real assets as those of infrastructure projects, for which there would be little or no historical data available. Recently, some new approaches to real option modeling have thus been developed which help to cope with the difficulty inherent in the assessment of the volatility of real assets, namely fuzzy logic and fuzzy sets [23].

Even though scenarios and real options have complementary strengths and weaknesses, the two streams of research have rarely crossed [24] [25]. While both of these techniques have been adopted separately (and largely) in different industries, little evidence exists as to their integration, especially due to the different inputs they provide [26] [27].

In real options modeling, alternative scenarios have the potential to help estimate changes in the present value of investment decisions, particularly when there are favorable and unfavorable events that can impact the expected value of future free cash flows. On the other hand, the main issue stemming from the use of scenarios in real options modeling is the difficulty to reduce the outcomes of the different scenarios to a single expected value of the investment.

This paper aims to improve investment decisions under uncertainty in the planning and project studies domain by exploring how scenarios and real options might be effectively combined to provide a valid alternative to the traditional DCF approach – an alternative which allows project decision-makers to decide more effectively whether and when they should spend their limited budget resources on new transportation projects. Specifically, we address the following research question: *How can policy makers integrate scenarios and real options to better manage the uncertainty of the long-term costs and benefits of transportation infrastructure projects?*

The paper is structured as follows. First, we consider our research within the existing literature on scenarios, real options, and the management of uncertainty of infrastructure projects. Next, we develop an innovative methodological approach to managing such uncertainty and apply this approach retrospectively to the empirical case of a major transportation infrastructure project in Rome, Italy. Finally, we critically evaluate the main advantages and disadvantages of the proposed methodology against the traditional DCF technique and its implications for the management of transportation projects. We show that combining scenarios and real options can be very helpful in developing a more comprehensive understanding of the long-term effects of infrastructure projects and thus in selecting the most relevant projects. Overall, our study can assist the debate over the assessment of costs and benefits of complex infrastructure projects and their role in promoting economic development.

## II. TRANSPORTATION INFRASTRUCTURE PROJECTS, SCENARIOS, REAL OPTIONS, AND UNCERTAINTY MANAGEMENT

### *A. Uncertainty management of transportation infrastructure projects: conventional investment analysis techniques*

Previous studies have emphasized that improvements in transportation infrastructure yield significant benefits to direct users. According to Vickerman et al. [28], such improvements consist of shorter travel times and better scheduling, which create new location advantages, reduction of travel costs as a result of shorter distances, ease of traffic flow, reduced congestion, and higher speeds [29]. Transportation infrastructure services also reduce fuel consumption, air pollution, and capital and labor costs (e.g., [30] [31] [32]). Scholars have also explored the short- and long-term effects of transportation infrastructure on the economy, which manifest in increases in employment during the development of the infrastructure and enhanced convenience for households and increases in real estate prices if land values rise due to a trade-off between transport costs and accessibility [33] [34]. Venables [35] emphasizes that all such 'wider economic benefits' should be considered in an ex-ante evaluation of long-term returns of such projects.

However, the uncertainty of long-term effects of transportation infrastructure projects represents a key challenge for national and regional governments – a challenge that is particularly severe because of lifecycle length and the complexity (a broad range and diversity) of the outcomes of such projects [36] [37]. Coping with uncertainty has been observed to be a vital element of major infrastructure planning and development processes, in which both the lack of relevant and reliable data ('known unknowns') and the nature and range of future socially constructed events ('unknown unknowns') pose a significant threat to major infrastructure evaluation and approval (e.g., [38] [39]).

In this respect, growing uncertainty has driven project management research toward new opportunities and challenges [40] [41]. Despite the debate over the long-term effects of transportation infrastructure projects, we still know relatively little about how to manage the uncertainty of such effects. In particular, to date, scholars have focused on the use of conventional investment techniques by highlighting the benefits – and at the same time, the limitations – of such approaches.

Specifically, the most common techniques for assessing the long-term returns and costs of infrastructure projects are ‘conventional’ investment appraisal techniques, i.e., payback (PB), return on assets or investment (ROA or ROI), and capital budgeting tools, such as NPV and IRR, based on DCF (e.g., [42] [43]). Among these approaches, DCF, NPV and IRR can be considered the dominant methods. The main reason that justifies the widespread application of capital budgeting tools to project investments is essentially related to the intuitive simplicity of the go/no-go investment decision. DCF provides a single numerical outcome, the discounted net present value of the project: if the DCF value is above zero, the project is a go, while if it is below zero, the project is rejected [44].

The DCF approach calculates the value of an expected stream of cash inflows less an expected stream of cash outflows discounted at a given rate. This method assumes that an investment decision is made either at the beginning of a project or never [45]. This feature implies two major limitations: first, DCF may take into account a random walk (statistical dispersion) of costs and benefits, but not their respective volatility, because the degree of variation of trading prices over time are unavailable; second, it ignores the opportunity to profit from new information about key changes in the external environment as long as this information becomes available [46].

Major infrastructure investments have specific characteristics, particularly in regard to uncertainty and capital budgeting over long periods of time [47] [8]. The application of traditional financial investment appraisal methods fails to include the random probability distribution of the critical inputs to the project value over time, and hence potentially results in incorrect valuations of strategic long-term infrastructure investments [35]. In deterministic valuation models, such as NPV and DCF, the output of the model is fully determined by the parameter values and the initial conditions. In contrast, stochastic models (i.e., real options) possess some inherent randomness. The same set of parameter values and initial conditions will lead to boundaries of a ‘statistical space’ where the project value is free to float at each given time [48]. The value of uncertainty and volatility embedded into large infrastructure investments remains difficult to evaluate using conventional financial techniques, which suggests that the management of such uncertain investments may particularly benefit from different approaches based on stochastic models [49].

### *B. Alternative approaches to project evaluation: scenarios and real options*

#### *1. Scenarios*

A promising alternative approach to project evaluation relies on scenarios; it has been used extensively by business strategists since the 1960s, with the most notable example being the Shell case in the oil industry [50]. Since then, scenarios have been further used to increase the robustness of long-term investment plans by leading firms of many different industries and by policymakers in tourism (e.g., [51]), environmental studies (e.g., [52]), urban water infrastructure (e.g., [53]) and urban planning (e.g., [54]). However, the application of scenario planning in transportation research has only recently captured the attention of scholars and practitioners [55]

[56]. Due to computer simulation tools supporting spatial data visualization and interactive analysis, considering scenarios has allowed decision-makers to explore the future outcomes and benefits of selected transportation and water infrastructure projects. To improve the robustness of Innovate UK’s decision-making under uncertainty, in 2015/2016 it commissioned the development of a set of scenarios to explore the role of future technology for future transport. This approach was used to explore potential impacts on different stakeholders in the society and consider policy interventions that were consistent across a range of scenarios [57]. Similarly, in 2020, Transport Scotland published its revised National Transport Strategy in which its underlying thinking and formulation have been informed by a scenario planning tool and process [58].

Instead of predicting the future, the main rationale of scenarios is to consider alternative views of the future in the form of different (but internally consistent) configurations of key drivers of change in the business (or project) environment [17]. The most common use of scenarios for transportation and infrastructure projects has mainly shown deductive reasoning to be required to focus on the arising uncertainties (i.e., new events or drivers of change) in the project environment and then to select, among all of such arising uncertainties, the most critical ones to be used as the basic premises of a small number of scenarios [59]. However, although the potential of this method has long been emphasized by strategic scholars, its use in the management of transportation infrastructure projects has been curbed by its recognized limitations.

In this regard, the scenarios’ value added depends strictly on their consistency, which relates to the ability to capture coherently within each scenario the mutual influences of many drivers of change. Despite the availability of different approaches to scenario building (e.g., deductive vs.

inductive approaches), consistency is strongly dependent on the knowledge and skills of the managers involved in this process. While consistent scenarios are likely to help decision-makers change the mental models they inherit from previous experience (and overcome the inertia inherent in such experience), inconsistent scenarios are likely to contribute to organizational inertia instead by leading to mental models that are not aligned with the real future [17]. Another relevant limitation of scenarios is the lack of systematic approaches to measuring the future outcomes of each scenario. The qualitative focus of scenarios often leads managers to overlook the task of quantifying the future value of drivers of change, and the lack of quantitative data ultimately reduces the vividness – and the value added – of scenarios [24]. Even in the case of financial modeling and investment appraisal, where scenarios are meant to estimate changes in the value of future cash flows, the need to consider different and multiple scenarios at the same time leaves decision-makers with the difficult (and therefore often simply omitted) task of reducing such multiple scenarios to a single "most likely" expected value of the investment [60]. Finally, it is worth noting that considering scenarios requires participants to be motivated, involved and in a good disposition to prevent biased decisions and dominant personalities from prevailing, which might limit the range of alternative scenarios that are eventually described and fully considered [24].

### *2. Real options*

Further to scenarios, a key approach to uncertainty management increasingly emphasized by strategic scholars and practitioners is that of real options. Although the literature has quickly expanded to considering a large number of increasingly complex models for the analysis and valuation of real options, its underlying reasoning is based on a quantitative approach rooted in finance research (e.g., [45]). The real option approach extends financial option theory to nonfinancial or ‘real’ assets. This perception places real options at the intersection of strategy and finance, where the Black-Scholes model prices the right but not the obligation to make an additional investment, based on five key factors, namely the exercise price, the asset value, the time left until the expiration, the risk-free rate and the project’s volatility. Over time, a number of different real option valuation models have been developed; however, all of them utilize an algorithm similar to the Black-Scholes partial differential equation, which can only be used if the expected variance of returns (the volatility) is known [61].

The real options technique is significantly different from the traditional discounted cash flow (DCF) approach due to allowing managerial investment flexibility and the dominant role of volatility in determining the future value of the investment. Real options theory emphasizes the flexibility inherent in the opportunity (but not the obligation) to invest further in additional assets, which thus allows decision-makers to profit from favorable outcomes and avoid losses.

The real options approach has been applied first to a wide range of domains, including the oil, energy, pharmaceutical, and telecommunication industries, where the underlying project or asset (e.g., oil, energy or medicines) is traded in perfect markets in which information about the asset is available freely and is reflected in the asset price [16]. Although more examples of the use of real option valuation have emerged in recent years in the field of infrastructure [62] [63], there is still little evidence of this technique’s application to transportation projects, where DCF remains by far the dominant investment appraisal method [42] [64]. The lack of a frictionless market for infrastructure assets and, consequently, the difficulty of tracking daily market prices makes the statistical determination of volatility unfeasible; consequently, a calculation of the solution of the Black-Scholes partial differential equation remains impossible or largely subjective if we use surrogate volatility data for similar (‘twin’) assets [23]. This quite likely represents the main barrier to the application of real options to appraisal of investments in transportation infrastructure, where the volatility of key parameters is unknown.

As a result, although the real options technique has been increasingly used in valuing infrastructure investments, most of published cases focus on projects where the volatility of output prices and cost inputs can be determined or derived with the use of advanced statistical methods, such as Monte Carlo simulations [65]. In projects where the distribution and dispersion of key variables is unknown or unreliable, decision-makers have embraced real option reasoning to define the options attributable to the initial investment following an informal and heuristic process that can lead to future-proof outcomes [66].

### *C. Advantages and disadvantages of DCF, scenarios and real options*

Table 1 summarizes the main benefits and challenges of DCF, scenarios and real options for infrastructure projects’ evaluation and the management of such projects’ uncertainty.

**Table 1.** Benefits and challenges of DCF, scenarios and real options

| Method | Benefits | Limitations |
|---|---|---|
| **DCF** | Intuitive simplicity of the investment decision rule: if DCF > 0 then go; if DCF < 0 then abandon [44]<br>A simple and univocal link between a strategy and its financial value [67] | Historic volatility of costs and benefits is not available [45]<br>Ignores the value of active management, and the ability to profit from new information [61] |
| **SCENARIOS** | Alternative visions of the future [17]<br>Externally focused: scenario planning helps managers continuously explore opportunities and threats [68]<br>Qualitative approach and system thinking [50] | Multiple scenarios cannot be easily reduced to a single “most likely” expected value of the investment [60]<br>Need for internal consistency [17]<br>Bias of participants due to the influence of dominant personalities [24] |

| | | |
|---|---|---|
| | Flexibility and adaptation of strategic investment decisions [69]<br>Coordination and communication: creation of a language and shared understanding among decision-makers [70] | |
| **REAL OPTIONS** | The Black-Scholes model is one of the most important concepts in modern financial theory. It involves a stochastic equation that estimates the future value of capital investments, taking into account the impact of time and other risk factors [71]<br>Emphasis on flexibility to postpone, stop or expand irreversible investments in real assets [72] | Difficulty of valuing options on real assets since doing so requires the calculation of volatility of the underlying asset price, which is the fundamental driver of real option value. The value of the volatility of real assets is unclear or is entirely unobservable. No option value can be determined without the knowledge of volatility [66]<br>Loss of links to the environment: most of real option valuation models do not provide clear guidelines for selecting key drivers of change and exploring their likely evolution [24]<br>Unrealistic assumptions about quantitative financial skills of decision-makers. Senior management usually lacks mathematical skills required to apply, understand and communicate real option valuation [73] |

Overall, such benefits and limitations – coupled with the growing uncertainty of transportation infrastructure projects – call for the design and application of new management approaches integrating both strategic and financial analysis such as scenarios and real options, using ideas that might be borrowed and adapted from other research streams in management and economics [74].

The use of scenarios and real options in transportation management is particularly promising, as infrastructure projects are generally framed in terms of various sequential phases, i.e., planning and zoning, construction and post-construction [75]. This feature is consistent with the underlying principles of real options and scenarios. It is therefore quite surprising that the combined use of real options and scenarios has remained underexplored thus far by scholars and practitioners in the field of transportation research.

In the following sections of the paper, we aim to bridge this gap in the existing literature by developing a new methodological approach that systematically combines real options with scenario planning. The method we propose aims to foster real option reasoning by simplifying the use of the Black-Scholes option pricing model in a way that allows decision-makers to calculate the financial value of alternative scenarios.

## III. COMBINING REAL OPTIONS AND SCENARIOS FOR EVALUATING TRANSPORT INFRASTRUCTURE INVESTMENTS

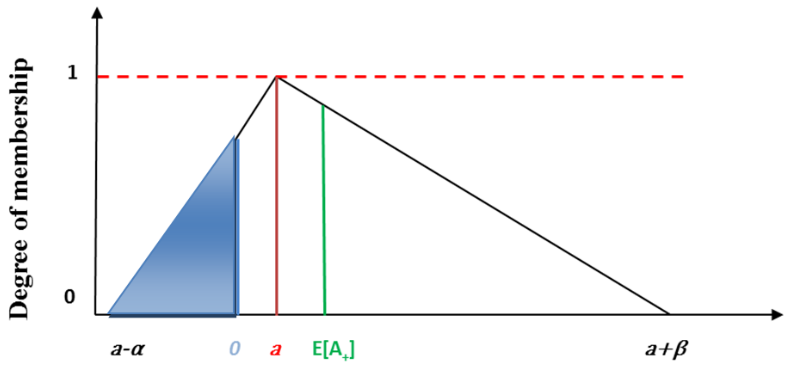
The methodology we develop and illustrate in this paper builds upon the previous work of Favato and Vecchiato [25], who already attempted to embed real options into scenarios for assessing the long-term value of a new drug in a biotech start-up. Despite being rooted in the same deductive approach of scenario planning and the payoff model of real options, the methodology we propose in this paper is significantly different. First, although the underlying real option reasoning is essentially the same as that in the published biotech case, the scenarios elicited here reflect the specific economics of transportation infrastructure by considering the idiosyncratic benefits and stages of development of investments of this type (as previously identified in the review of the existing literature; see [28]). By doing so, we show that the payoff model of pricing real options we use in this paper can be easily transferred to a variety of construction industries and project specifications. Second, the biotech application priced a staging option to develop an innovative medicine, where uncertainty was directly related to the outputs of clinical testing and the consequent possibility of meeting regulatory requirements in terms of efficacy and safety of the new medicine. In the case illustrated by this paper, we price an option to expand an existing infrastructure project with already committed financing. We retrospectively apply our methodological approach to the case of the north extension of the third underground line in Rome (Line C). This transportation infrastructure case provides a compelling research setting, given the uncertainty in the nature and the quantification of the benefits to direct users. By doing so, we inherently demonstrate that the payoff model of pricing real options, combined with scenarios, is a useful tool for managers of infrastructure projects since it allows pricing all types of real options, including staging, expansion, abandonment, delay, or switching of the infrastructure to a different use. Finally, while the biotech case describes the method of making an investment decision by a privately held company that is free to choose the valuation tools and the model inputs that it believes are better proxies of the financial value of the project, in the transportation case we discuss here a publicly funded project, where the investor was a public entity (the municipality of Rome), and the variables to be included in the valuation of the incremental investment needed to expand metro Line C were codified by national laws [76]. In this case, our model passed a severe test, since the degree of freedom in choosing the value drivers was extremely limited. The value drivers were defined a priori, hence the application of our proposed method to the case of the Rome underground's Line C ('Rome Line C') suggests that this method has the flexibility to be adapted to virtually any infrastructure investment decision.

In the remainder of this section of the paper, we illustrate first our overall methodological approach to the integration of real options and scenarios; in the next Section 4, we then apply it to the case of Rome Line C and compare the outcomes of our method with those of the traditional DCF approach.

*A. Payoff model for valuing real options of infrastructure projects*

Among the recent studies in the literature on real options, the payoff model developed by Collan et al. [77] features a fuzzy logic approach to valuation of investments under uncertainty, which makes it particularly suitable for cases in which input information takes the form of cash-flow scenarios (fuzzy sets) and the volatility of cash flows is unknown or unavailable but can be described with a degree of probability ranging from 0 (extremely unlikely) to 1 (certainty) [75]. These characteristics make the payoff model a good fit for the appraisal of investment in new transportation infrastructure projects. This method calculates a real option value for a project from the project's payoff distribution (an NPV distribution) that can be constructed from the project's cash-flow scenarios. The created NPV distribution is treated as a fuzzy number. According to [77], the method utilizes fuzzy sets to determine the possibilistic – as opposed to probabilistic – expected value of a given investment project. The fuzzy distribution shown in Figure 1 simplifies reality and assigns the highest degree of possibility (1, meaning 'fully possible') to the 'base' case (or the middle case) and the lowest (approaching 0) degree of possibility to the minimum and maximum values of the distribution. The result is a triangular fuzzy distribution of returns on investment (hence, the payoff distribution).

**Figure 1.** Triangular distribution of the payoff model



The payoff distribution was originally created using three discounted cash-flow scenarios [77]:

1) A 'worst'-case scenario based on the lowest credible estimates of costs and benefits,
2) A 'best'-case scenario based on the highest credible estimates of costs and benefits, and
3) A 'base' scenario based on an intermediate outcome in which costs and benefits are neither maximized nor minimized.

The outcomes outside the worst-case and best-case scenarios will not be considered by the payoff model, and therefore the included values define the payoff distribution of the project's discounted cash flows, which is treated as a fuzzy set.

The choice of three scenarios (base, best and worst) is particularly relevant to the appraisal of infrastructure investments since previously published cases referred to a high, medium or low attractiveness of safeguarding such investments according to uncertainty and modularity of the empirical observables in transportation projects [78]. The adoption of the payoff method allows us to match real option reasoning with the development of distinct scenarios. The latter lead to the estimation of discounted cash flow values that are subsequently consolidated into a single univocal value of the investment under uncertainty. This value is calculated as the payoff value of fuzzy sets represented by the three scenarios (base, high and low), and the calculation of uncertainty does not require any measure of dispersion, such as volatility. The use of three reference scenarios, the ability to consolidate three discounted cash flows into a single value under uncertainty, the applicability of the method to projects with unknown volatility, and the intuitive visual representation of the decision space (a triangle) represent the key advantages of this method for management of infrastructure projects.

Depending on the sign of the base case (positive or negative) and the sign of its relative distance from the best-case and worst-case scenarios, the real option's value can be calculated as shown below:

$$E(A_+) = \begin{cases} a + \frac{\beta - \alpha}{6}, & if\ 0 < a - \alpha \quad 'all\ NPV\ positive' \quad (1) \\ \frac{(\alpha - a)^3}{6\alpha^2} + a + \frac{\beta - \alpha}{6}, & if\ a - \alpha < 0 < a \quad 'some\ negative\ NPV; positive\ peak' \quad (2) \\ \frac{(\alpha + \beta)^3}{6\beta^2}, & if\ a < 0 < a + \beta \quad 'some\ positive\ NPV; negative\ peak' \quad (3) \\ 0, & if\ a + \beta < 0 \quad 'all\ NPV\ negative' \quad (4) \end{cases}$$

The real option value calculated from the fuzzy DCF is the possibilistic mean value of the fuzzy DCF values E(A+) multiplied by the positive area of the fuzzy DCF and divided by the total area of the fuzzy DCF:

$$Real\ option\ valuation = \frac{\int_0^\infty A(x)dx}{\int_{-\infty}^\infty A(x)d(x)} E(A_+) \qquad (5)$$

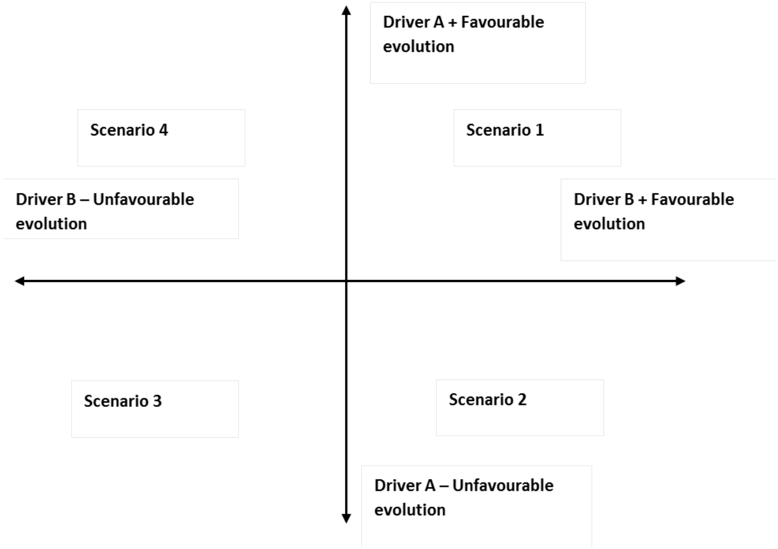
In this equation, A represents the fuzzy DCF, E(A+) is the possibilistic mean of the positive area of the payoff distribution, $\int_0^\infty A(x)dx$ is the positive area of the payoff distribution, and $\int_{-\infty}^\infty A(x)d(x)$ is the total area of the payoff distribution. This calculation method is aligned with the real options' valuation logic, which implies that the management will interrupt or modify a project when its payoff becomes negative [76].

Due to the triangular distribution of fuzzy set A+, the positive value of its fuzzy mean E (A+) can be obtained simply by calculating the negative area (the blue triangle in Figure 1) as a percentage of the total area of the triangle a-α;1; a + β. This value can be easily determined without integration. The missing value (Y' of the apex of the blue triangle) can be obtained by a calculation using the linear equation of the line defined by two points: X= a; Y=1 and X= a-α; Y=0. Then, we must solve the linear equation for X=0 to obtain the Y value of the apex of the blue triangle (Y' in Figure 1). Next, the negative portion of E A(+) can be easily calculated as (a-α x Y')/2. The negative value as a percentage of the total can be obtained by simply dividing the area of the blue triangle by the total area of fuzzy set A (a-α +a + β/2); then, the positive percentage value of E(A+) can be obtained by subtracting the negative percentage from 1. If we apply the last percentage value to the calculated E(A+), the option value will be obtained without the use of integration: this approach offers a significant advantage for policymakers in terms of modelling the distribution of the payoff model because, in contrast to the complexity of the Black and Scholes [19] model, the mathematical hurdle of this approach is minimal.

### *B. Deductive approach to scenarios*

The deductive approach to scenarios is particularly suited to the payoff model of real option valuation [79]. This approach is based on the initial identification of the two most important variables (i.e., drivers of change) that can affect the outcomes of a given strategic investment decision [68]. As alternative (opposite) assumptions are formulated with regard to the variables' future evolution pattern, these two critical variables become the axes of a 2x2 scenario matrix, as shown in Figure 2. For simplicity, we generically name such key variables “Driver A” and “Driver B”. As indicated in Figure 2, while one assumption about future evolution usually turns out to be the most favorable in terms of future outcomes, the other – namely, the opposite – assumption may have a negative impact.

**Figure 2.** Structure of a 2x2 scenario matrix



The 2x2 matrix provides a helpful framework for supporting the application of the payoff model. Specifically, this matrix allows the identification of four scenarios with significantly different impacts on the long-term return of an investment project.

Figure 2 shows that Scenario 3 is associated with the lowest expected DCF, and its 'double negative' scenario is likely to represent the worst-case input to the payoff valuation model. In contrast, the 'double positive' Scenario 1 represents the best-case input because it produces the highest credible estimates of benefits and the most favorable cost expectations. Finally, the 'base' scenario (i.e., that based on an intermediate outcome, where costs and benefits are neither maximized nor minimized) might be represented instead by either the 'positive-negative' scenario (Scenario 4) or the 'negative-positive' scenario (Scenario 2), depending on the different impacts of the key drivers (variables A and B) on the future outcomes (NPV) of the strategic investment decision.

Therefore, if the relative probabilities of occurrence of Scenario 2 (p') and Scenario 4 (p'') are known (p' + p'' = 1), then the input for the base case can be obtained by calculating a probability-weighted mean of the two discounted cash flows:

'base case' DCF = (DCF Scenario 2 x $p'$) + (DCF Scenario 4 x $p''$)

If the relative probabilities are unknown, then the mean value of the DCFs stemming from Scenario 2 and Scenario 4 is likely to be an acceptable approximation because it is assumed that the two scenarios will share the same degree of possibility (full possibility = 1) in the fuzzy distribution of project returns underlying the payoff model [76].

### *C. Combining real options and scenarios*

By combining a 2x2 scenario matrix with the payoff model and real options' valuation, project decision-makers can obtain a more comprehensive overview of the long-term effects of major transportation infrastructure investments. The 2x2 scenario matrix described in Figure 2 can be seamlessly applied to the case of a transportation infrastructure project by exploring such a project's different sources of revenues and costs and selecting two of such revenues and costs as the basic drivers of the four alternative scenarios[1]. Based on these scenarios, the payoff model will enable the quantification of these revenues and costs and, ultimately, of the profits (value) of the project itself in a relatively simple yet accurate way.

In particular, a key feature of construction projects that facilitates the application – and increases the contribution – of the real options logic is that transportation infrastructure investments are generally framed around specific and different phases. These phases also follow a precise order

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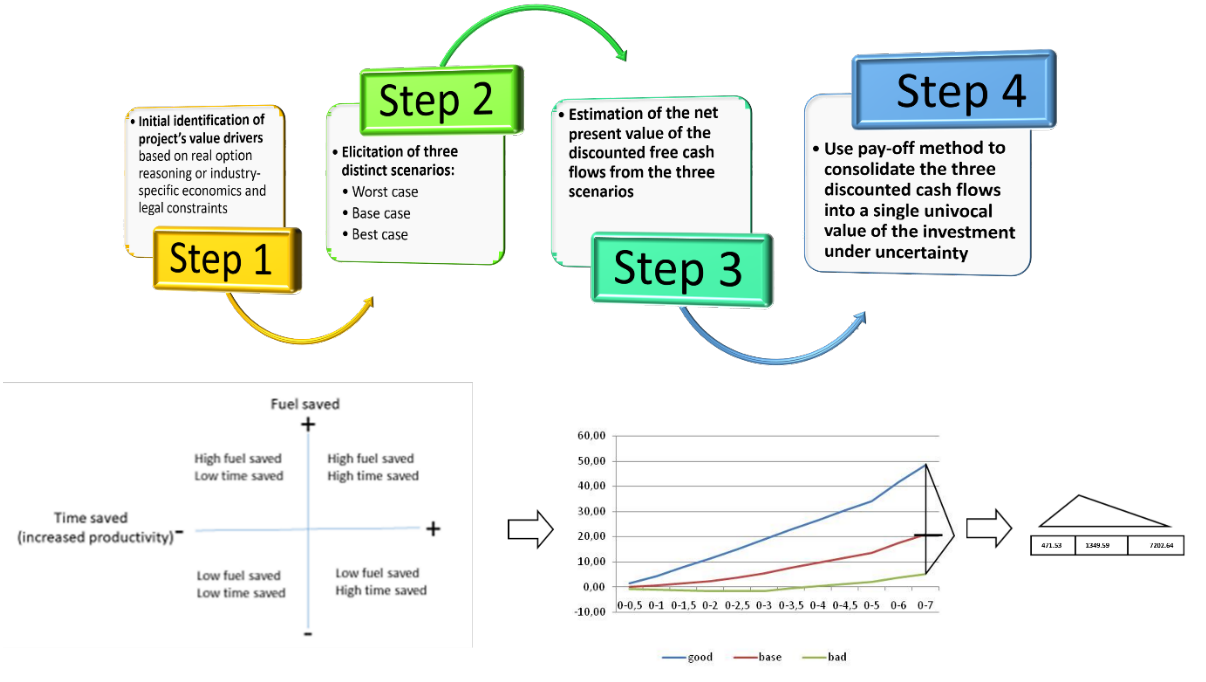
[1] The deductive approach would then explore the related evolution of the other drivers, in each scenario, in a way that is consistent with the assumptions made for the key drivers, thus allowing one to seamlessly increase the number of costs and benefits of transportation projects that are taken into account.

from feasibility studies, project definition, design, negotiation and pre-contract stages to construction and commissioning. Specifically, beginning from owning the land on which transportation infrastructure might be built, such a project can be divided into three main stages: planning and zoning, construction, and post-construction [75]. A prerequisite for beginning a transportation project is that the designated area be available for development. Land must often be purchased or leased for the purpose of the project, and the profitability level of the potential project to be built on the land determines the acceptable cost of obtaining the use of the land. The planning and zoning phase (Phase 1) consists of investment in urban development prior to construction and entails steps such as acquiring or leasing the land (where necessary) and planning the area to be developed (e.g., designing the architecture, municipal engineering and infrastructure plans). After Phase 1, the construction phase (Phase 2) begins when the zoning is ready, and the construction permits are valid. This phase includes the construction and development of municipal engineering and infrastructure for the newly connected areas (e.g., buildings, roads, pipelines, lighting, and parking areas) and the construction of the planned transportation line. Finally, the post-construction phase (Phase 3) begins after the construction of the transportation infrastructure is ready and operational. This phase includes 'owning' the service and maintenance of the infrastructure constructs [75].

Each of the three phases requires specific investments and generates specific cash-flow revenues. Furthermore, the duration of each phase is difficult to estimate accurately because of a number of factors that are often associated with the high complexity and uncertainty of major infrastructure projects [75]. Each phase gives policymakers the right – but not the obligation – to proceed to the next phase. The real option logic – combined with scenario planning – is very helpful for precisely capturing the value of this right and thus can provide policymakers with a more accurate tool than the traditional DCF approach to help them decide whether to invest in a transportation infrastructure project.

In Figure 3 we provide a flowchart summarizing the main steps of our methodological approach to the integrated use of scenarios and real options for infrastructure project.

**Figure 3.** Flowchart of the integrated use of scenarios (deductive approach) and real options (pay-off model) for infrastructure projects



## IV. APPLYING OUR INTEGRATED APPROACH TO SCENARIOS AND REAL OPTIONS TO THE LINE C PROJECT OF THE ROME METRO

### *A. Research setting: Extension of Line C of the Rome underground*

To illustrate our innovative methodological approach to the assessment of the long-term benefits of transportation infrastructure projects, we apply it to the case of the extension of the third metro line in Rome (Line C). This project, which was under consideration in 2007, involved an estimated budget of approximately €1.6 billion and an estimated construction time of eight years. The tender was assigned by Roma Metropolitane (the Rome Metro), operating on behalf of the Municipality of Rome, and entailed the expansion of Line C's main route toward the northwest by creating additional sections labeled T1 (from Clodio/Mazzini to Farnesina) and C2 (from Farnesina to Grottarossa).

This project was framed around three phases; for simplicity, in this paper we focus on the first and second phases: (1) urban development prior to construction and (2) the construction of the new section of Line C underground. Specifically, we apply our methodology in the beginning of the planning and zoning phase (Phase 1: urban development) to calculate the value of the option to invest at that particular time and to eventually proceed with the construction of the two sections TI and C2 (Phase 2).

The dilemma faced by the Municipality of Rome was daunting and involved the questions of whether to invest an estimated amount of €761.71 million to undertake Phase 1 and obtain enough information to make an informed stop/go decision regarding the development of Phase 2, and whether it would be worthwhile to proceed with the project and invest an additional amount of €825.17 million, the direct estimated cost of building the new Line C extension. This decision was critical for the Municipality of Rome, which aimed to improve the connection of the northern part of Rome with the city center.

To decide whether the extension should be built, Roma Metropolitane and the Municipality of Rome applied the traditional DCF technique using the NPV, which led to a negative value, and the decision in 2007 to not proceed with this infrastructure project.

Note that the value obtained by our method combining scenarios and real options will be compared at the end of this section with the NPV obtained by Roma Metropolitane. To fully highlight the different outcomes of our method, we consider in its application exactly the same official data that were used by the policymakers of the Municipality of Rome and the project decision-makers of Roma Metropolitane when they calculated the NPV and made their final decision. In contrast with the latter and the NPV method, we show that the uncertainty of the project can be reduced by framing this decision as a real option: the amount of €761.71 million should be regarded not only as an opportunity for the urban renewal of the northwest area of Rome but also as the price of the option to proceed to the construction of sections T1 and C2 (Part 2). If the option value is greater than the cost of Phase 1 development (the option price), the Municipality of Rome should invest; otherwise, the extension of Line C should be terminated immediately.

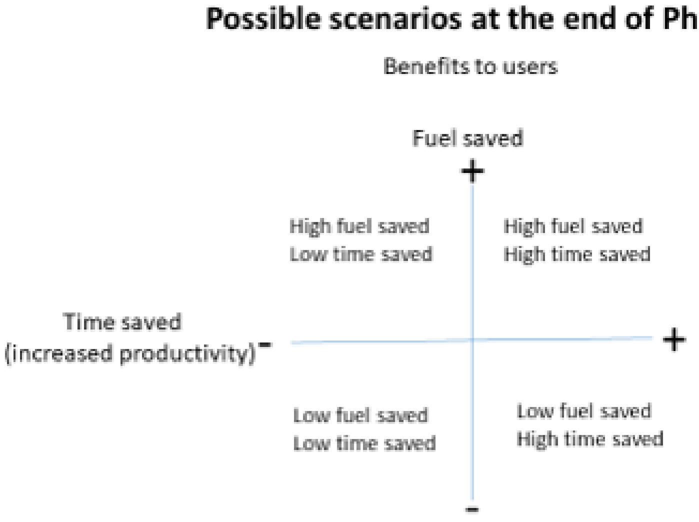
To evaluate the costs and benefits of the extension of Line C, Roma Metropolitane performed a thorough feasibility study in 2007, including a) mobility studies, b) forecasting demand for transportation services, c) a simulation of the transportation network's services and traffic flow calculations, and d) estimates of CO2 emissions and fuel consumption [80].

Along with quantitative mathematical models (e.g., automatic vehicle monitoring during peak hours), qualitative interviews were used by the Municipality of Rome to determine citizens' travel habits in the urban areas affected by Line C extension. The cost/benefit analysis was performed over a project lifecycle period of 36 years (8 years of construction and 28 years of operation) and included both infrastructure investments and operating costs. According to the preliminary study performed in 2007, the overall investment required for Phase 1 amounted to €761.71 million, while that required for Phase 2 amounted to €825.17 million. Roma Metropolitane identified two key benefits of the proposed extension of Line C to users: (1) time savings in the course of business travel (i.e., increased productivity) and (2) the reduced use of cars (i.e., fuel savings). These main categories of benefits were used by Roma Metropolitane to estimate the long-term value of the project and are consistent with the mainstream planning and project studies literature [34] [35]. Therefore, they are used in this paper as the cornerstone of the illustrative application of our methodological approach.

*B. Alternative scenarios for Line C of the Rome Metro*

The 2x2 matrix in Figure 4 describes the four possible scenarios for the development of the new northwest extension of the metro's Line C at the end of Phase 1 (urban development prior to construction). The four scenarios result from different (alternative) courses of evolution of the future benefits for users, namely, increased productivity and fuel savings.

**Figure 4.** Possible scenarios for Rome Line C northwest extension at the end of phase 1



The scenario in which both benefits to users are large is the 'best-case scenario' (the upper-right scenario in Figure 4). The scenario in which both of these benefits are instead small is the 'worst-case scenario' (the bottom-left scenario in Figure 4). The 2x2 matrix also includes two intermediate scenarios: one assuming the attainment of large benefits of the project in terms of fuel saved and small benefits in terms of time saved in the course of commuting (the upper-left scenario of Figure 4) and the other assuming the attainment of large benefits in terms of time saved and small benefits in terms of fuel saved (the bottom-right scenario of Figure 4). The 'base-case' scenario can be determined as an average state of these intermediate scenarios, i.e., the upper-left and bottom-right scenarios in Figure 4. For consistency, to determine the base-case scenario in this paper, we considered the inputs used by Roma Metropolitane in 2007 [80] in its DCF analysis to determine the value of the extension of Line C of Rome's underground (as described in the next section). The data were obtained directly from the cost-benefit study that was available to the Municipality of Rome and the project decision-makers of Roma Metropolitane in 2007 [80]. Additional inputs to the model included the incremental operating annual costs (€-10.06 million), the negative externalities of extra time spent on local public transportation (€-2.10 million), a discount rate calculated to be 5% and a VAT rate of 20% (as of 2007).

The relevant inputs for the direct drivers of benefits are summarized in Table 2 below.

The 'worst-case' scenario offers no significant benefits to the future users of Line C, and therefore in this case the Line C expansion option should be discontinued.

**Table 2.** Inputs to DCF and the PAYOFF valuation. Source: [80]

| **DIRECT IMPACT** | **Base case** | **Downside (-)** | **Upside (+)** | **Source: [80]** |
|---|---|---|---|---|
| **INPUTS as % of BASE CASE values** | | | | |
| Time saved (increased productivity) | 100% | 40% | 500% | Feasibility study by the Rome Municipality; page 171 |
| Reduced use of cars (fuel savings) | 100% | 40% | 500% | Feasibility study by the Rome Municipality; page 172 |
| **INPUTS' VALUE (€ millions actualized at 2008)** | **Base case: Rome Municipality's DCF valuation** | **Best scenario** | **Worst scenario** | |
| Time saved (increased productivity) | 105.89 | 529.43 | 42.35 | Source of the base case: cost/benefit analysis by the Rome Municipality |

| | | | | |
|---|---|---|---|---|
| Reduced use of cars (fuel savings) | 30.10 | 150.50 | 12.04 | Source of the base case: cost/benefit analysis by the Rome Municipality |
| **SCENARIO ANNUAL VALUE (€ millions)** | *135.99* | *679.93* | *54.39* | |

| **ADDITIONAL INPUTS TO THE MODEL** | **Values** | | | |
|---|---|---|---|---|
| Incremental operating annual costs (€ millions) | -10.06 | | | Feasibility study by the Rome Municipality; page 169 |
| Negative externalities (extra time spent on TPL - € millions) | -2.10 | | | Feasibility study by the Rome Municipality; page 171 |
| Discount rate | 0.05 | | | Feasibility study by the Rome Municipality; page 169 |
| **TOTAL INVESTMENT** | 1322.40 | | | Feasibility study by the Rome Municipality; page 169 |
| Total investment including VAT at 20% | 1586.88 | | | |
| Capex attributable to Metro construction (Phase 2) | 687.64 | | | Feasibility study by the Rome Municipality; page 169 |
| Capex including VAT at 20% | 825.17 | | | |

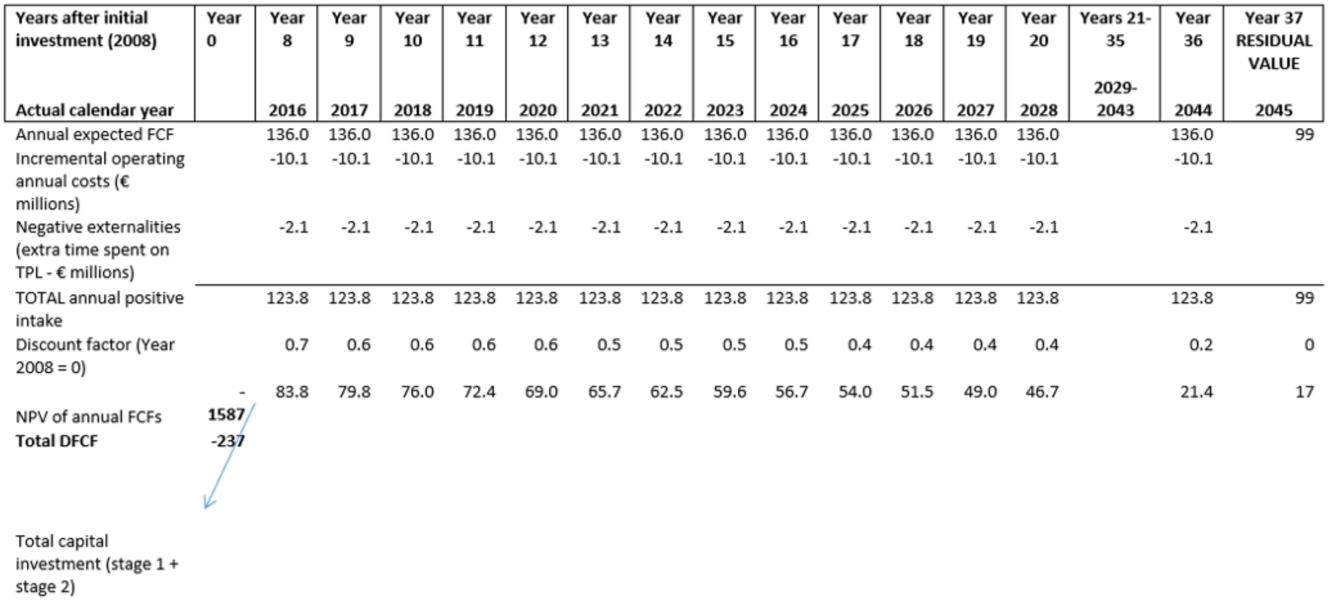
*C. Using scenarios to apply the payoff model and calculate the value of Line C extension*

In 2007, once the feasibility study and the collection of documentation related to Line C extension were completed (in the beginning of Phase 1), the Municipality of Rome had a clear expansion option. The latter can be defined as an embedded option that allows the organization that purchased a real option to expand its operations in the future at little or no cost [72]. The expansion option, unlike typical options that gain their value from an underlying security, gains its value from the flexibility it provides to a company. Once the initial stage of a capital project has been completed, an expansion option's holder can decide whether to proceed with the project.

As indicated earlier in this section, we used the DCF projections used by the Rome Municipality to appraise the investment opportunity as our base case. The DCF model is shown below in

Table 3.[2] The values are actualized at the 2008 value; hence, the columns are identical. All years have been included in the discounted free cash flow model, and both the discounting and the total cash flows reflect the entire planned timeframe (36 years) of the investment. We maintained as terminal value the input used by the Rome Municipality (99 million euros) for all scenarios, discounted over 35 periods similarly to the last year of cash flows, following the common practice in DCF valuation [81].

**Table 3.** DCF valuation accepted by the Rome Municipality and the consequent no-go investment decision. Source: [80]



| **Years after initial investment (2008)** | **Year 0** | **Year 8** | **Year 9** | **Year 10** | **Year 11** | **Year 12** | **Year 13** | **Year 14** | **Year 15** | **Year 16** | **Year 17** | **Year 18** | **Year 19** | **Year 20** | **Years 21-35** | **Year 36** | **Year 37 RESIDUAL VALUE** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Actual calendar year** | | **2016** | **2017** | **2018** | **2019** | **2020** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029-2043** | **2044** | **2045** |
| Annual expected FCF | | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | 136.0 | | 136.0 | 99 |
| Incremental operating annual costs (€ millions) | | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | -10.1 | | -10.1 | |
| Negative externalities (extra time spent on TPL - € millions) | | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | -2.1 | | -2.1 | |
| TOTAL annual positive intake | | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | 123.8 | | 123.8 | 99 |
| Discount factor (Year 2008 = 0) | | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.5 | 0.5 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 | | 0.2 | 0 |
| | - | 83.8 | 79.8 | 76.0 | 72.4 | 69.0 | 65.7 | 62.5 | 59.6 | 56.7 | 54.0 | 51.5 | 49.0 | 46.7 | | 21.4 | 17 |
| NPV of annual FCFs | **1587** | | | | | | | | | | | | | | | | |
| **Total DFCF** | **-237** | | | | | | | | | | | | | | | | |
| Total capital investment (stage 1 + stage 2) | | | | | | | | | | | | | | | | | |

After the base case was chosen, the best and worst cases were obtained by varying the main inputs according to the expected volatility estimated by a feasibility study performed by the Rome Municipality prior to completing the investment's performance evaluation. Then, the payoff model was seamlessly used to calculate the value of the option to invest in Phase 1 (urban

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[2] Please note that for conciseness, we do not report values from year 25 to year 31 after the beginning of the project.

development prior to the construction of the project infrastructure) of Line C extension. Table 4 reports the main inputs used in the payoff model to calculate the real option value of the project.

**Table 4.** DCF of the 3 scenarios (worst, base and best) included in the real option valuation and calculation of the payoff value of the option to expand.

| **Years after initial investment (2008)** | **Year 0** | **Year 8** | **Year 9** | **Year 10** | **Year 11** | **Year 12** | **Years 21-35** | **Year 36** | **Year 37 RESIDUAL VALUE** |
|---|---|---|---|---|---|---|---|---|---|
| **Actual calendar year** | | **2016** | **2017** | **2018** | **2019** | **2020** | **2029-2043** | **2044** | **2045** |
| **Annual Cash Flows: WORST CASE SCENARIO** | | 54 | 54 | 54 | 54 | 54 | | 54 | 99 |
| Incremental operating annual costs (€ millions) | | -10 | -10 | -10 | -10 | -10 | | -10 | |
| Negative externalities (extra time spent on TPL - € millions) | | -2 | -2 | -2 | -2 | -2 | | -2 | |
| TOTAL annual positive intake | | 42 | 42 | 42 | 42 | 42 | | 42 | 99 |
| Discount factor (Year 2008 = 0) | | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | | 0.2 | 0.2 |
| Discounted Annual Cash Flows | | 29 | 27 | 26 | 25 | 24 | | 7 | 17 |
| **Total Discounted Cash Flows** | **471.53** | | | | | | | | |
| **Annual Cash Flows: BASE CASE SCENARIO** | | 136 | 136 | 136 | 136 | 136 | | 136 | 99 |
| Incremental operating annual costs (€ millions) | | -10 | -10 | -10 | -10 | -10 | | -10 | |
| Negative externalities (extra time spent on TPL - € millions) | | -2 | -2 | -2 | -2 | -2 | | -2 | |
| TOTAL annual positive intake | | 124 | 124 | 124 | 124 | 124 | | 124 | 99 |
| Discount factor (Year 2008 = 0) | | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | | 0.2 | 0.2 |
| Discounted Annual Cash Flows | | 84 | 80 | 76 | 72 | 69 | | 21 | 17 |
| **Total Discounted Cash Flows** | **1349.59** | | | | | | | | |
| **Annual Cash Flow: BEST CASE SCENARIO** | | 680 | 680 | 680 | 680 | 680 | | 680 | 99 |
| Incremental operating annual costs (€ millions) | | -10 | -10 | -10 | -10 | -10 | | -10 | |
| Negative externalities (extra time spent on TPL - € millions) | | -2 | -2 | -2 | -2 | -2 | | -2 | |
| TOTAL annual positive intake | | 668 | 668 | 668 | 668 | 668 | | 668 | 99 |
| Discount factor (Year 2008 = 0) | | 0.7 | 0.6 | 0.6 | 0.6 | 0.6 | | 0.2 | 0.2 |
| Discounted Annual Cash Flows | | 452 | 430 | 410 | 390 | 372 | | 115 | 17 |
| **Total Discounted Cash Flows** | **7202.64** | | | | | | | | |
| Possibilistic value of Total Discounted Cash Flows | 2178.8 | | | | | | | | |
| Less initial capital investment | -825.17 | | | | | | | | |
| = DISCOUNTED FREE CASH FLOWS | 1353.63 | | | | | | | | |
| Less option price | -761.71 | | | | | | | | |
| = Real Option value | **591.92** | | | | | | | | |

As shown in a visual representation of the real option value of Phase 1 of the Rome metro's Line C extension, the possible cumulative DCF over a period of 28 years (€2,178,8 million) less the capital investment required for Phase 2 (construction) of €-825.17 gives a possibilistic NPV of Phase 1 of €1,353.63 million. Therefore, the possibilistic NPV-OPTION PRICE (the Phase 1 urban development cost of €761.71 million) implies a positive real option value (ROV) of €591.92 million. The ROV embedded in the investment decision at the end of Phase 1 of the planning and zoning of the Rome Line C extension is thus large and positive (€591,92 million), contrary to a negative expected value of the investment (€ - 237,34) derived from a deterministic DCF approach; hence, the investment should not be turned down since it could possibly contribute to the economic development of the city of Rome.

Based on this evidence, in 2007 the Municipality of Rome should have committed €761.71 million to begin the extension of the metro's Line C (Phase 1 development). Not only should the positive value per se of the real option embedded in the incremental capital investment have convinced the management to go ahead with the investment project – but also the public managers should have recognized that the outcomes were based on inputs with truly unpredictable variability. Any new information about the benefits of the project can change the set of assumptions underlying the DCF at any moment. This aspect is essentially related to the undiversifiable risk that drives the returns on major infrastructure and transportation projects. However, using the payoff model, public managers can set the upper and lower limits of the estimates based on the current acceptable range of uncertain values. This 'space' determines a possibilistic value of the real option including all possible values within the minimum/maximum range chosen to define the scenarios. The main factor that should lead to a 'go' decision is the confidence to connect managers' inputs (the DCFs of the alternative scenarios) with 'possible' mean returns with a distribution that can be visualized in the shape of a simple triangle. The intuitive representation of uncertainty about future returns obtained with the payoff model allows the management to confidentially reason about the key drivers of value embedded in the DCF, i.e., the benefits of the transportation infrastructure, and to blend their mutually exclusive patterns of evolution (in the different scenarios) into a coherent and comprehensive measure of value: the real option.

The approach combining scenarios and real options illustrated in this paper established a direct and immediate connection between the main categories of benefits used by Roma Metropolitane (i.e., benefits to users) and the four possible scenarios leading to the option value of the Rome metro's Line C extension at the time of the investment decision (the beginning of Phase 1).

In the case of the Rome metro's Line C, the ROV calculated with the payoff model is large and positive (€591.92); hence, the Municipality of Rome should have invested in the urban development project (Phase 1); in doing so, it would have bought the option to proceed with the construction of the new northwest line extension later (Phase 2). By investing in the first phase of the project, the Municipality of Rome would have acquired the right but not the obligation to eventually build the new Line C route by postponing the timing of the actual irreversible capital investment necessary to construct the new infrastructure (Phase 2). Once the option to expand had been purchased and the urban development had been completed, Roma Metropolitane, acting on behalf of the Municipality of Rome, could periodically reassess the estimated values of the indirect benefits; therefore, the city would have time to decide whether to proceed in building the new Line C route. The extension would occur only if the benefits to the direct users were positive.

### *D. Line C extension: comparing the outcomes of the combined scenarios/RO approach with those of the traditional DCF approach*

In 2007, the leading policymakers of the Municipality of Rome and the project decision-makers of Roma Metropolitane based their understanding of the outcomes of Line C extension on the traditional DCF approach, calculating the NPV in the beginning of Phase 1 [80]. Overall, the result obtained through the DCF model differed significantly from that of the payoff model (as applied in the previous section of the paper). While the NPV was negative (-€237.34 million), leading to the decision to reject the investment in the extension of Line C, the real option value (as determined in the previous section) was large and positive, and it should have led to the opposite decision to carry out the investment instead.

This comparison thus clearly indicates the benefits of our innovative methodological approach and, more generally, of the possibilistic – as opposed to probabilistic – expected value of a given investment project. More precisely, the combination of scenarios and real options helps policymakers capture new information about relevant changes in the economic landscape surrounding a major infrastructure project as long as such information becomes available, whereas the NPV approach ignores the benefits related to the ability to delay (or stop) irreversible investment decisions. Therefore, a relevant difference is how the combined use of real options and scenarios enables a systematic approach to transportation infrastructure project evaluation that encompasses a broad range of benefits to different categories of stakeholders.

While our method identified four different scenarios arising at the end of the first phase of the project, the DCF approach ignored the existence of different phases and treated the project as a single irreversible scenario from the very beginning of the project. Such determinism inevitably led to an underestimation of the overall benefits of the proposed Line C extension and, ultimately, of its long-term value. Consequently, as of 2021, construction of Line C underground remains to be completed, and the delay in the development of the main route of Line C contributed to a dismissal of the Line C extension.

## V. DISCUSSION

In this paper, we design and apply a new methodological approach aimed at helping project decision-makers cope with the uncertainty of transportation infrastructure projects by enhancing their ability to assess the value of long-term effects (costs and benefits) of such projects. Specifically, the innovative approach that we illustrate in this paper is designed to allow project decision-makers to (1) develop a shared understanding of the potential benefits of major investment projects in transportation infrastructure, (2) select projects that are most likely to contribute to economic growth and focus their resources on such projects, and (3) reduce the financial risks inherent in major investment projects by regarding such projects as consisting of different steps, each entailing the right but not the obligation to proceed forward to the next step. Overall, the methodological approach we propose in this paper helps project decision-makers and policymakers facing tightening budget constraints optimize their long-term investment plans [7] [35] [37].

Table 5 summarizes the main advantages of our innovative methodological approach by comparing it with the techniques of scenarios and real options used separately to manage transportation projects.

**Table 5.** Comparison of our combined methodological approach to using scenarios and real options with (the limitations of) each individual technique

| Limitations of scenarios and real options (when used separately) | Advantages (integrated use of scenarios with real options) | Source of benefits |
|---|---|---|

| | | |
|---|---|---|
| Difficulty of valuing options on real assets (real options: [66) | The payoff model does not require managers to evaluate the volatility of the future benefits and costs of the transportation infrastructure (contrary to the case of established methods such as Black-Scholes) | Payoff model |
| Timing of exercise (real options: [66]) | The 2x2 scenario matrix combined with the payoff model allows project decision-makers to obtain a flexible analytical framework for deciding when to proceed with the next phase of development of the transportation infrastructure | 2x2 scenario matrix combined with the payoff model |
| Loose links to the external environment of the project infrastructure (real options: [24]) | The 2x2 scenario matrix provides a clear narrative about future costs and revenues (benefits). Based on these dynamics, project decision-makers can clearly link real options analysis with the likely evolution of the transportation infrastructure | Scenarios: qualitative approach/data |
| Unrealistic assumptions about managerial skills (real options: [16]) | The payoff model requires relatively simple statistical and mathematical skills | Payoff model |
| Biases (scenarios: [24]) | Quantitative data provide a more objective basis for identifying the long-term value of transportation projects | Real options: quantitative approach/data |
| Lack of quantitative data (scenarios: [17]) | Real options provide quantitative data that enable managers to turn the narrative of scenarios into the financial effects of external changes and new events affecting the future evolution of a transportation project | Real options: quantitative approach/data |
| Lack of consistency (scenarios: [24]) | Quantitative data helps check the internal consistency of each scenario (e.g., by comparing the value of the same driver of change in the four alternative scenarios related to the long-term evolution of the project) | Real options: quantitative approach/data |

The integration of scenarios and real options approaches might offer a viable solution for minimizing project decision-makers' bias by directing their attention toward the most beneficial projects. The methodological approach discussed in this paper requires the explicit disclosure of the choice and value of key project's drivers used to inform the three scenarios. By doing so, the assessment of competing investment decisions becomes necessarily more transparent and reduces potential bias in project planning and approval (e.g. [2] [3]). Using this approach, managers can explore the long-term patterns of evolution of the effects of alternative transportation infrastructure projects and convert different future scenarios into clear cash flow projections in a systematic yet relatively simple way by supporting strategic discourse and a real option reasoning approach (e.g., [63] [66] [78]). In particular, the main contribution of real options is highlighting how transportation infrastructure projects can evolve over time and providing an opportunity to obtain and process new information that creates value for users. The application of real options – especially the payoff model combined with scenarios – has the potential to offer a more disciplined decision-making process than the traditional DCF approach for not only the evaluation of transportation projects but also their timing. The NPV logic is biased in favor of the early investment commitment because it considers only the risk of waiting (preemption of scarce assets) without recognizing the advantages of waiting (a reduction of uncertainty). In the case of Line C extension, taking into account the possibility of modifying (i.e., postponing) major investment decisions based on the new information that becomes available over time might allow the managers of Roma Metropolitane to reconsider the choice to invest in Phase 1 (planning and zoning) and thereby to acquire the right – but not the obligation – to proceed with Phase 2 (construction) later.

The combined use of scenarios and real options can also help prevent the occurrence of cases in which uncertainty stops or causes the denial of approval of projects that in fact have the potential to create long-term value for users [82]. As a result, we hope that our research will ignite the debate over the costs and benefits of transportation infrastructure investments in relation to the nature, size and timing of such costs and benefits [28] [29] [30] [31]. The combined use of real options and scenarios can help improve the transparency and collegiality of decision-making processes of different project stakeholders by preventing the dominant players and personal interests from prevailing and by fostering a dialog among different institutional players, especially direct users [83]. On the one hand, our innovative methodological approach to assessing the long-term benefits of transportation infrastructure builds upon the previous work of Favato and Vecchiato [25], who initially explored the topic of combining the payoff model of real options and the deductive logic of scenarios. However, the above study was focused on the specific case of a biotech company in which the identification of the key variables for the axes of the scenarios was straightforward and idiosyncratic. In the biotech industry, the long-term profits of a new drug depend on its efficacy and safety compared with those of the main drug that is currently the dominant product (or standard of care). The variables of efficacy and safety were thus used as the main axes of the scenarios [25]. In addition, the above study focused on the idiosyncratic phases related to the development of new drugs (i.e., preclinical testing, studies involving patients to estimate efficacy, and clinical studies entailing a comparison to the current best-available treatment).

Despite sharing the same roots of the payoff model and the deductive logic of scenarios, this paper develops a different approach that is unique to the specific case of transportation infrastructure. First, it considers the idiosyncratic phases (i.e., the planning and zoning phase, the construction phase and the post-construction phase) of such investment projects. Second, and more importantly, it focuses on the assessment of the long-term value of the costs and benefits of infrastructure projects by leading to a more accurate and comprehensive estimate of such costs and benefits.

The application of our methodology to the case of the northwest extension of Line C of the Rome underground also revealed several limitations of this methodology. First, it is important to recognize that the quantification of future benefits of transportation infrastructure projects still depends on the knowledge of experts involved in the preliminary analysis of such benefits. In other words, our methodology is meant to assist project decision-makers in exploring the data on benefits and assessing their future value; the identification of such benefits (e.g., their nature and likely size) is a fundamental prerequisite for the effective use of real options and scenarios themselves.

Second, a critical issue in the application of our methodological approach entails the conversion of the intermediate scenarios of the 2x2 scenario matrix (i.e., scenarios '+;-' and '-;+') of Figure 3 into the base scenario for the payoff model. In the proposed example, we identified the base-case scenario on the basis of the main estimates proposed by Rome Metropolitane itself in calculating the NPV of the project. In the absence of a framework for deriving the base-case scenario or assessing the relative probabilities of the intermediate scenarios of the 2x2 scenario matrix, policymakers can assign the same likelihood (i.e., 50%) to the intermediate scenarios themselves and then determine the base-case scenario of the payoff triangle as a simple average of the two. However, this simplified approach might lead to an inaccurate – albeit slightly so – estimate of the value of the real option.

Third, the Line C extension was a relatively easy project. For the sake of simplicity, we also applied our integrated scenarios and real options approach to the first and second phases of the Line C extension, thereby ignoring the costs and benefits related to the service and maintenance of the infrastructure constructs (Phase 3: see [75]). Furthermore, for our illustrative case to be consistent with the available data, we based the application of our method on the same costs and benefits used by Roma Metropolitane in 2007 to calculate the NPV of this project. On the one hand, we might thus have overlooked the impact of some other costs and benefits which are recognized in the extant literature on transport projects (e.g., benefits due to reduced pollution or an increase in real estate value) [35]. On the other hand, the flexibility of the scenario planning approach allows us to seamlessly increase the number of costs and benefits of transportation projects that are taken into account by our proposed method.

Finally, it is worth mentioning that our methodological approach has never been used (ex-ante) on infrastructure projects, and no data was empirically collected on the feelings and beliefs of decisionmakers on its applicability.

## VI. CONCLUSIONS

The aim of this paper is to contribute to the planning and project studies literature by exploring how the integrated us of scenarios and real options might support investments under uncertainty, by allowing project decision makers to better select the new transportation projects in which they should spend their limited budget resources (e.g., [26] [27]). Our paper fills a practical gap in relation to the embedding or real options in scenario planning as well as a theoretical gap.

So far, scenarios and real options have generally developed as separate approaches to uncertainty management, with these methods having different theoretical premises and nature (i.e., scenarios: qualitative approach based on expert's and managers' opinions; real options: quantitative approach based on the collection and used of formalized data) and different objectives (scenarios: fostering a strategic conversation process which allows decision makers to adapt their mental models; real options: improve the accuracy of the calculation of future investment outcome). Our paper contributes to the extant literature by discussing how the combined use of scenarios and real options help advance each individual technique, by complementing their different (qualitative vs. quantitative) premises and objectives.

The outputs of scenarios and real options have been found to be more reliable and effective when these techniques are integrated, as the weaknesses of one technique turns to be the strength of the other [16] [17] [24] [25].

Our work has some clear limitations, including its retrospective use in past projects rather the ex-ante application in future ones. However, we hope that, despite these limitations, future research efforts might improve the accuracy and reliability of our framework by applying it to different types of infrastructure projects. More generally, we hope that our work might spur the investigation of innovative approaches which move away from traditional (static rather than dynamic) DCF-based methods of project evaluation, by driving project studies research toward new opportunities and challenges [40] [41].

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