PUBLIC WORKS MANAGEMENT AND POLICY

A System Dynamics Approach to Concession Period Optimization in Public-Private Partnerships (PPPs)

Castelblanco, Gabriel a
De Marco, Alberto b
Casady, Carter B. c, d, e

a University of Florida, Gainesville, FL, United States
b Politecnico di Torino, Torino, Italy
c Stanford University, Stanford, CA, United States
d George Mason University, Fairfax, VA, United States
e University College London (UCL), London, United Kingdom

ISSN 1087724X

DOI 10.1177/1087724X251314427

Publisher SAGE Publications Inc.

ABSTRACT

The success of public-private partnerships (PPPs) often depends on the duration of a project's concession period. Although experts have invested considerable efforts into optimizing these periods, few have examined the complex, interactive effects of project-specific risks and bankability criteria on the concession duration. To overcome this gap, this study develops a System Dynamics (SD) model that allows decision-makers to estimate the optimal concession period terms based on causal interactions between a project's main risks and bankability. The model is validated using data from 11 healthcare PPPs in Italy. The results show variable interest rates, inflation, operational expenditures (OPEX), and debt repayment mechanisms all uniquely impact the concession period.

Keywords

Public-Private Partnerships (PPPs); Concession; Risk; Bankability; System Dynamics; Healthcare

INTRODUCTION

Public-private partnerships (PPPs) use project finance principles to help fiscally constrained governments deliver large public infrastructure projects (Damnjanovic et al. 2016; O'Nolan and Reeves 2018). These projects typically involve the transfer of significant financial and managerial responsibilities to the private sector (Casady and Geddes 2019; Ortega et al. 2016), who in turn aim to satisfy the long term financial expectations of lenders and equity investors (Ashton et al. 2012; O'Nolan and Reeves 2018).

One of the key distinguishing features of a PPP is its financial structure, where a special purpose vehicle (SPV) is created to raise debt and pay for the project based on future projected cash flows (Yescombe 2014). Under this nonrecourse financial scheme, the corporate income statements and balance sheets of private firms involved in the project are shielded from liability in the event of project default, leaving lenders to scrutinize the project's creditworthiness and capability to provide sufficient cashflows for debt repayment (Kong et al. 2008). Moreover, the capital structures of PPPs tend to be highly leveraged, limiting the proportion of private equity required but increasing the potential return on investment (Weber et al. 2016).

The financial structuring of PPP projects often influences the estimated duration of the concession period, including design, construction, operations, and maintenance of the infrastructure facility. The length of this period also defines the window of opportunity for revenue collection (Zhang et al. 2016). To promote competition and optimize PPP costs, some governments select preferred bidders based on the shortest concession duration (Askar and Gab-Allah 2002; Auriol and Picard 2013). Others, however, set fixed concession periods to avoid overly aggressive bidding in procurement that may lead to ex-post renegotiations (Carbonara et al. 2014; Vecchi et al. 2022). Regardless of the criteria used, public and private partners need to reliably estimate the concession period of these long-term, complex, and uncertain projects in order to balance considerations of value for money for the government and its users against the profitability of the SPV.

Although experts acknowledge the importance of accurately estimating the concession period in PPP projects (Hanaoka and Palapus 2012; Xu and Moon 2014), few if any studies thoroughly incorporate risk profiles and bankability considerations into these estimates. Additionally, since the 2008-2009 global financial crisis (GFC), an increasing number of projects have failed to reach financial close or experienced significant delays under worse debt conditions because they failed to consider such risks (Regan et al. 2011; Zhu and Chua 2018).

The available literature currently suggests conducting multiple Net Present Value (NPV) analyses to determine the concession period, but these analyses neglect issues related to bankability and simply consider specific financial risks (Jin et al. 2019) and construction risks (Xu and Moon 2014). Other approaches place emphasis on risk management and win-win negotiation approaches (Carbonara et al. 2014; Hanaoka and Palapus 2012; Shen and Wu 2005). However, bankability criteria are often overlooked and key financial parameters and ratios are not a major factor in such analyses, such as Debt Service Coverage Ratios (DSCR) - i.e., the multiple by which net operating income fulfills the debt service (Regan et al. 2017) -, which are largely used to determine leverage in PPPs. Therefore, the PPP literature still lacks analyses that integrate these risks and bankability criteria into estimations of the optimal concession period.

To overcome this gap in the literature, this study developed a system dynamics (SD) model that allows decision makers to estimate a realistic concession period using both risk and bankability criteria. This methodology was chosen because of its ability to analyze complex relationships within systems to explain the underlying mechanisms that produce feedback loop outcomes (Sterman 2000). Moreover, SD reveals causal mechanisms within the system (i.e., feedback loops) and models them quantitatively (Sterman 2014).

The rest of this paper is organized as follows. First, relevant literature on previous studies estimating PPP concession periods is presented, as is the relationship between concession periods, risk, and bankability criteria. Next, the methodology for the SD model is outlined in detail. This is followed by a description of the dataset and process used to validate the model. Then, the results are presented and interpreted. Finally, this paper concludes by summarizing the practical and theoretical implications of the study and providing directions for future research.

LITERATURE REVIEW

Financial Drivers of the Concession Period

Project finance has become a dependable financing technique to develop infrastructure projects around the world (Yescombe and Farquharson 2018). Using this financing arrangement, project companies, also known as SPVs or concessionaires, are created to provide the necessary investment for the project as a single-purpose capital asset (Higham et al. 2017). The SPV is financed with nonrecourse debt and sponsor equity during the concession term (Weber et al. 2016). Return on investment is based on the project's revenues (i.e., ability to generate cash flow) during the concession period, in accordance with project finance standards (Higuchi 2019).

The concession period—i.e., the time frame a private investor has the right to operate and collect revenue from the project—thus serves as a critical component during PPP project negotiations because this remuneration period has significant financial implications for both the public and private sector partners. For a PPP to be economically viable, the revenues collected from the public sector and/or users must cover the concessionaire's expected profit plus the PPP life-cycle costs during the concession period (Higham et al. 2017). If the PPP concession period is too short, the concessionaire will likely reduce investments in operations and maintenance to improve profitability, resulting in lower levels of service and the potential for renegotiations (Zhang et al. 2018). In contrast, a long concession period may be harmful to the interests of users and the public sector and often result in detrimental conditions for the facilities when PPPs are transferred back to the government after the concession period ends (Khanzadi et al. 2012). As a result, determining an optimal concession period is crucial to the success of a PPP project.

Traditionally, concession periods are determined based on the maximum length allowable under the national PPP legal framework (Zhang et al. 2018). However, such a simplistic approach is often insufficient for addressing the complex, dynamic factors that impact PPP success. The most frequent method decision makers use to establish the length of concessions is based on the net present value (NPV) of revenue (Nguyen et al. 2021). This method considers various factors related to cash inflows and outflows over the PPP lifecycle, creating feedback loops and long-term impacts (Kong et al. 2008).

The PPP financial structure is also based on two sources: financing (i.e., debt and equity) and funding (i.e., public subsidies and user payments). Therefore, under predetermined risk allocation criteria, the project's financial structure is built using project finance standards to evaluate the revenues required for a minimum return on concessionaire's equity after covering debt repayments, OPEX, and CAPEX (Higuchi 2019). The main factors that impact the concession period are related to cash flow, including expected revenues, CAPEX, OPEX, and financing costs which are affected by inflation and the project's risk profile (Carbonara et al. 2014). The NPV method allows for a more accurate consideration of these factors and therefore offers a more realistic assessment of the concession period (Nguyen et al. 2021).

However, the success of PPP projects is far from assured, and there have been numerous examples of PPP failures worldwide because the established concession period proved to be insufficient for covering costs and maintaining profitability. These failures resulted in financial losses for both the public and private sectors, damaging public confidence in PPPs and impeding the development of future PPP projects. Several factors, such as unforeseen operating costs and the materialization of certain risks, have previously been identified as leading causes of failure in estimating the optimal concession period (Carbonara et al. 2014; Khanzadi et al. 2012). However, other factors, including financial risks and bankability are often ignored (Ullah et al. 2018). Failure to consider these factors can lead to significant project cost overruns, delays, or outright failures (Jin et al. 2019; De Marco and Mangano 2017).

To address the uncertainty surrounding demand forecasts and risks associated with external factors, the development of flexible-term contracts emerged (Engel et al. 2001). Under these contracts, the discount rate and tariff schedule are established, and firms submit bids based on the present value of revenues required to finance, build, operate, and maintain the infrastructure (Vassallo and Soliño 2006). The bidder with the lowest bid wins the concession, which ends once the present value of user fees collected equals the winning bid. This results in a contract term that adjusts automatically to demand shocks, significantly reducing demand risk borne by the concessionaire. Such an approach yields several additional benefits. First, demand risk is mitigated since demand fluctuations and revenue variations are reflected in the length of the contract. Since revenue is in present value terms, the duration of the contract does not affect PPP profitability, resulting in more incentives to reduce costs. For example, in Engel et al. (2001), flexible-term contracts reduced demand risk in highways by 30% compared to fixed-term contracts, resulting in cost savings. Second, there is no need for traffic demand guarantees to make the project bankable. A PPP typically requires 20-30% equity, which means the project must obtain financing for the remaining amount. This can be difficult to obtain without a government guarantee. Flexible-term contracts do not require these guarantees, which can be costly to the state in the event of a severe crisis. Furthermore, flexible-term contracts correct a significant deficiency of fixed-term PPPs. PPP contracts are typically designed to be inflexible to limit the risk of creeping expropriation by the government, making it difficult to incorporate early termination clauses to avoid opportunistic behavior. However, under flexible-term contracts, the government has the option to unilaterally buy back the concession by paying a fair price for the contract (Engel et al. 2020). This fair price is equal to the difference between the bid and the present value of toll revenue already collected, with a sum subtracted for savings in maintenance and operational costs. Third, in contrast to fixed-term PPPs where changes in user fees result in increased revenue risk for the concessionaire, flexible-term contracts allow for the adjustment of user fees without jeopardizing attainment of the winning bid's revenue.

Relationship Between Project Risk Profiles and Business Models

The relationship between project risk profiles and business models is also complex, dynamic, and heavily influenced by the nature and scale of the risks involved. In effect, risks can have a major impact on the economic viability of projects, as well as their ability to attract investment and secure financing (Marcellino et al. 2022). This is because risks can lead to significant financial losses and liabilities, which can undermine the financial sustainability of these projects and make them less attractive to investors and lenders (De Marco and Karsybayeva 2013).

The risk profile of PPPs often stipulates the likelihood and potential impact of events that could affect the project's cost, schedule, or performance (De Marco and Karsybayeva 2013). The risk profile may be influenced by a variety of factors, including technical complexity, legal and regulatory requirements, market conditions, financial risks, and environmental risks (Carbonara et al. 2014). The risk profile for PPPs is usually higher than traditional procurement methods because these projects involve an extended period of involvement between both parties across multiple lifecycle phases, from planning and design to construction and operations (Roehrich et al. 2014).

The business model for a project defines its structure, including the roles and responsibilities of the public and private partners as they pertain to things such as financing, revenue, and risk (Weber et al. 2016). The PPP business model must be carefully designed to ensure that the project is financially feasible and risks are appropriately allocated (Cruz and Sarmento 2021).

The relationship between a PPP project's risk profile and business models is complex. A higher risk profile typically requires a more significant financial investment from the private partner, which, in turn, affects the business model. In effect, the private partner may require a higher return on investment to compensate for the higher risk, resulting in higher user fees or concession payments

(Sumirat et al. 2020). The business model must, therefore, be designed to balance the risk and return for both parties.

Moreover, the risk profile can also impact the choice of delivery model. For instance, a design-build-finance-operate (DBFO) model may be preferable for a project with a lower risk profile, while a design-build-finance-operate-maintain (DBFOM) model may be more suitable for a higher risk project. The DBFOM model transfers maintenance risk to the private sector, whereas the DBFO model retains this risk with the public sector.

To mitigate the impact of risks on PPP projects, it is important to adopt appropriate risk management strategies that are tailored to the specific nature and scale of these risks. This requires a comprehensive understanding of the risks associated with specific infrastructure types as well as the technical, financial, and regulatory challenges they may present. One approach to managing risk in PPP projects is adopting a risk-sharing business model, which involves sharing risks and rewards between the public and private sector partners (Cruz and Marques 2012). This approach helps ensure both parties have a vested interest in the success of the project and are incentivized to adopt best practices in risk management. Another approach involves optimizing project design and development in order to improve the economic viability of PPP projects and reduce financial risks as well as other potential liabilities. Reducing their impact also enhances PPP's social and environmental sustainability (Li et al. 2023).

System Dynamics in the PPP Literature

System Dynamics (SD) modeling is a useful methodology for developing complex models driven by feedback loops and nonlinear behaviors. SD was developed to support decision-making in various fields, including PPPs. This approach seeks to expose the relationships among the system's variables to assess diverse scenarios under complex environments. SD models systems based on rules, operations, and delays built upon interwoven stocks, flows, and variables that evolve permanently. Quantitatively, these models incorporate differential equations to model the evolution of stocks using feedback loops and their causal interactions, thereby exposing systems' counter-intuitive behaviors and their underlying structure (Sterman 2000).

Most of the previous SD models proposed have been limited to analyzing the impact of uncertainty of one isolated driver, such as financing or construction costs. Zhang et al. (2018) developed an SD model to examine the effect of maintenance performance on concession periods. Similarly, Alasad and Motawa (2015) developed an SD model focused on analyzing the effect of demand risk on toll roads. These models are restricted to analyzing the impact of specific isolated drivers while failing to consider the financial impact of critical risks across the whole PPP lifecycle.

Ng et al. (2007) conducted an analysis of how potential changes in the inflation rate, traffic flow, and operating costs might affect the concession period. Nevertheless, this model is hypothetical and neglects considering the impact of debt conditions and bankability criteria, such as the DSCR, on such concession periods. Zhang et al. (2020) proposed an SD model for the public sector to choose different combinations of equity and debt in PPPs, but this model neglects the effect of alterations in operation costs, debt conditions, and financial risks. Tavakoli and Hosseini Nourzad (2020) developed an SD model that considers PPP social benefits and uncertainty. However, this model fails to account for financial risks, debt conditions, and bankability criteria.

While traditional SD models in the PPP literature have been focused on analyzing the feasibility of PPP projects and establishing the optimal price (Ng et al. 2007; Zhang et al. 2020), there is a gap in the literature when it comes to examining the financial consequences of certain critical factors on PPP bankability and the concession period. Moreover, previous SD models have mostly been focused on toll roads and waste-to-energy PPPs (Song et al. 2015; Tavakoli and Hosseini Nourzad 2020). This article proposes an SD model that uses lifecycle cost analysis (LCCA) to estimate and validate a realistic concession period based on data from multiple healthcare PPPs, using both risk and bankability criteria as inputs. This approach offers a more holistic perspective that considers critical drivers such as financing, construction costs, operational costs, and project risks across all stages of the PPP lifecycle.

RESEARCH METHODS

SD concepts were used as the overarching methodological framework to develop the model (Sterman 2000), whose quantitative formulation is derived from project finance principles. Counterfactual experiments were conducted to identify potential decisions that the public sector, the SPV, and lenders may adopt to optimize the concession period when considering risks and bankability.

Data from eleven healthcare PPPs in the northwest of Italy were used for assessing the model (see Table 1). One of the authors acted as a consultant to the Regional Government Evaluation Board of PPPs and could collect first-hand data from the main contract documents of the PPPs under study.

Table 1. Summary of the Data Set

Parameter	Lower quartile	Median	Upper quartile	Standard deviation	Units
% Equity	10.5	17.9	25.4	14.8	%
% Public Subsidies	8.6	17.1	50.8	36.5	%
Concession Period	15	21	27.75	8.07	Year
Concessionaire CapEx	308.79	467.57	626.36	317.57	kEuros/year
Construction Cost	9859	10833	13788	38552	kEuros
Construction Period	1	1.5	4.3	10.53	Year
Interest Rate	1.26	2.38	3.73	1.38	Dmnl
Repayment Period	20	20	21	0.94	Year

The methodology integrates five stages. First, a literature review was conducted to identify the relationship between the concession period, risk, and bankability criteria. Second, a qualitative causal loop diagram was developed to depict in a conceptual way the feedback structures underlying the complex relationships that determine the concession period. Third, based on the literature and real data from the select healthcare PPP projects, a stock and flow diagram was developed for the simulation model. Next, statistical testing was used to measure the capacity of the model to capture the behavior and trends of real project data based on eleven healthcare PPPs. Lastly, a policy analysis was conducted to present specific decisions that stakeholders may adopt in order to optimize the concession period.

Simulation Model Definition

To unravel the complex relationships between the concession period, risk profile, and bankability, the proposed SD model analyzed coexisting feedback loops that explain the financial behavior of PPPs.

For the PPP project to be financially feasible, revenues gathered during the concession period must cover the capital expenditure, the operations and maintenance (O&M) cost, and the concessionaire's profit. Consequently, a shorter PPP concession period has an adverse effect on the concessionaire's investment return, leading to a lack of sufficient funds that may trigger suboptimal service levels and, consequently, affect users. Alternatively, a longer PPP concession period is highly detrimental to the interest of the public sector. To prevent this underperformance, an optimal concession period is essential for the long-term success of a PPP. Frequently, the PPP concession period is set as the longest duration permitted by the legal framework (Zhang et al. 2018). Such a simplistic approach neglects the numerous dynamic and uncertain factors that may affect PPP performance (Verweij et al. 2022).

Eq. (1) and Fig. 1 show that a reasonable concession period depends on the payback period when the NPV becomes positive. This can be affected by multiple factors related to cash flow. These factors dynamically interact with each other and lead to feedback loops and long-term impacts over the concession period. The public sector or government and the private investor need to account for these relevant factors when bidding and negotiating the concession period. Nevertheless, the total O&M costs affecting cash outflows during the concession period of a PPP project are often estimated as fixed values. In fact, the O&M costs are related to corresponding maintenance measures and timing, which may dynamically affect the performance services provided by the project, users' willingness to pay, cash inflows and outflows, and the NPV.

The proposed SD model calculates an optimal concession period based on revenues, CAPEX, capital expenditure depreciation, financial costs, and O&M expenditures in likely scenarios of underperformance. The LCCA approach is used to evaluate the impacts of multiple scenarios on the optimal concession period. For the NPV method, the project cash flow is presented as follows:

$$NPV(t) = \sum_{t=0}^{ts} \frac{R(\mathbf{t})-C(\mathbf{t})-O(\mathbf{t})-F(\mathbf{t})}{(1+r)^t} \geq 0 \qquad (1)$$

Where NPV(t)= net present value in year t; R($\mathbf{t}$)= revenues in year t. $C(\mathbf{t})$= capital expenditure (i.e., planning, designing, and construction); $O(\mathbf{t})$= operation expenses; F($\mathbf{t}$)= financial costs; t= concession period; and r= the expected rate of return.

The objective function is to achieve a non-negative NPV after the concession period ends. Moreover, the SD simulation model incorporates the mathematical equations, which are shown in detail in the Supplementary Section.

Causal Loop Model

A Causal Loop Diagram (CLD) provides a qualitative representation of the system's interconnection by showing causal influences between variables through positive or negative links. Positive links reflect changes in the same direction between the independent (arrow tail) and dependent (arrowhead) variables, and negative links show opposite differences between dependent and independent variables, including time delays (Armenia et al. 2021). Furthermore, multiple dependent variables can be linked through closed loops, which constitute feedback loops that can be either balancing (B) or reinforcing (R) (Sterman 2000).

The CLD presented in Fig. 1 conceptualizes the causal interaction between the *Concession Period*, bankability (as indicated by the *DSCR*), and the main risks affecting the project's expected cash flow. The diagram includes three balancing loops (red loops in Fig. 1) and three reinforcing loops (green loops in Fig. 1), explaining the causal structures that produce its characteristic performance and dynamics.

R1 and B1 show the coexisting positive and negative effects of *Financial Risk* on the *Concession Period*. Both loops share the following: a longer *Concession Period* means more *Financial Risk,* which also triggers higher *Inflation*. R1 emphasizes the detrimental effects of higher *Inflation*, such as higher *Interest Rates* and higher *OPEX*, that will lead to higher *Annual Debt Payments* and consequently a longer *Concession Period.* Simultaneously, B1 is focused on the beneficial effects of *Inflation,* such as subsequent increases in *Total Revenues*, which benefit the *SPV's Gross Cash Flow* and, consequently, lead to a shorter *Concession Period*.

R2 and B2 focus on the reinforcing and balancing effects on the *Concession Period* associated with *OPEX Risk* and the *Repayment Period*, respectively. In this regard, a longer *Concession Period* increases the *OPEX Risk*, which yields higher *OPEX*. This has detrimental effects on the *SPV's Gross Cash Flow,* resulting in a longer *Concession Period*. Conversely, a longer *Concession Period* increases the *Repayment Period* to lenders, which results in lower *Annual Debt Payments;* and consequently, helps reduce the *Concession Period.*

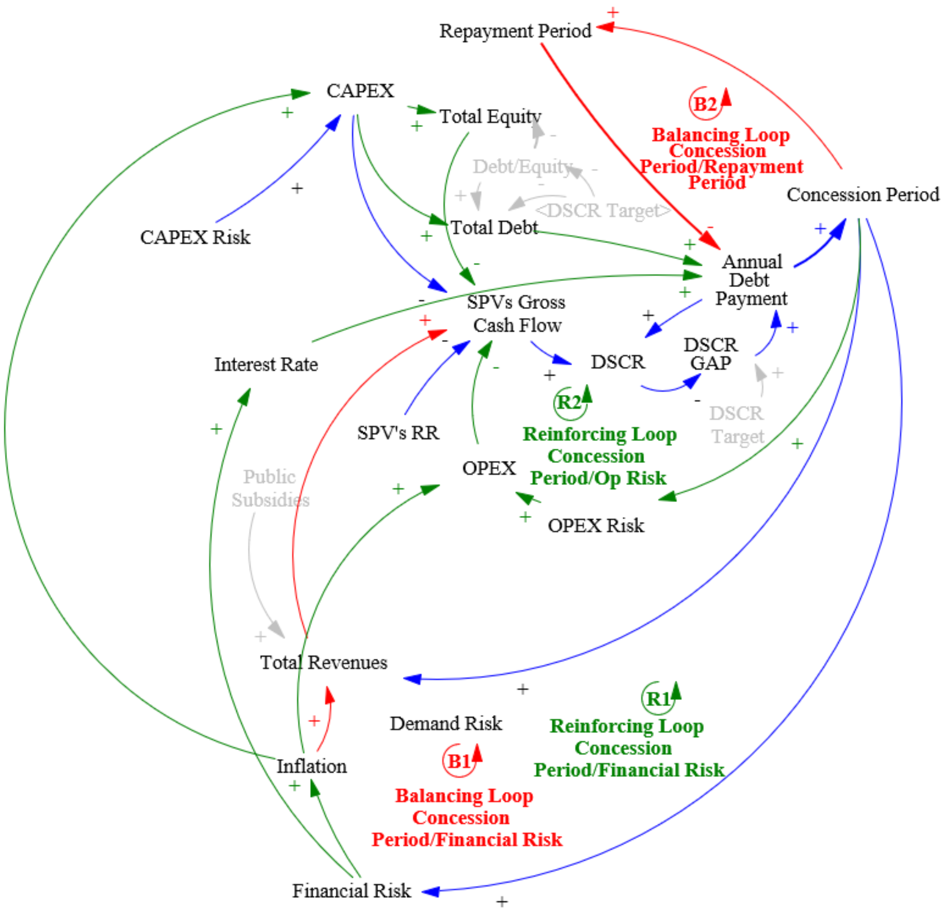

Fig. 1. Simplified Causal Model and Feedback Loops.

Quantitative Stocks & Flows Model

The Causal Loop was then expanded into a Stocks and Flows (S&F) model. To comprehensively incorporate the quantitative relationships required for the SD model, five subsystems were included within the boundary of the model, namely; CAPEX, OPEX, Revenues, Private Finance & Subsidies, and Cashflow subsystems.

The first subsystem is focused on the Capital Expenditure (CAPEX) to incorporate the costs incurred during the construction phase (Fig. 2). In this subsystem, the normalized *Construction Cost per Bed* and the *Infrastructure Capacity* (number of beds) constitute the *Yearly Construction Cost*. This cost is distributed on a yearly basis during the *Construction Period*. In general, the S&F model calculates costs in nominal terms to incorporate the effect of *Inflation* on costs and revenues.

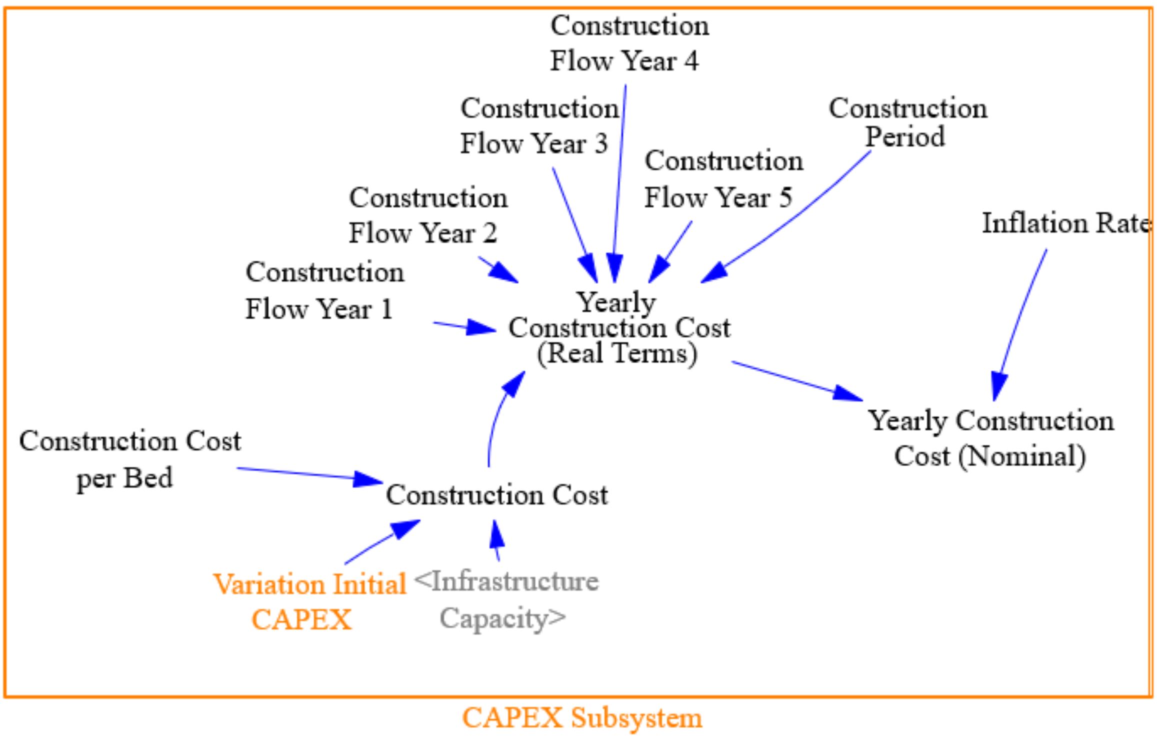

Fig. 2. CAPEX Subsystem

The OPEX Subsystem (Fig. 3) incorporates expenses associated with the O&M of ancillary services and facilities management. These costs may start either at the beginning of the concession period or after the construction phase ends, depending on contractual arrangements and the existence of such facilities. The *Total Operation Cost* is divided into two parts, the *Yearly Operation Costs* and the *Concessionaire's Costs* due to overhead expenses during the operating period. For healthcare PPPs, this subsystem links operating costs with the operation of commercial services and auxiliary activities along with the maintenance of built assets, utilities, and equipment, while the public sector is responsible for the operation and management of the core clinical service, along with the resources required for such services. The auxiliary services include information technology systems, security, waste management, cleaning, laundry, and catering.

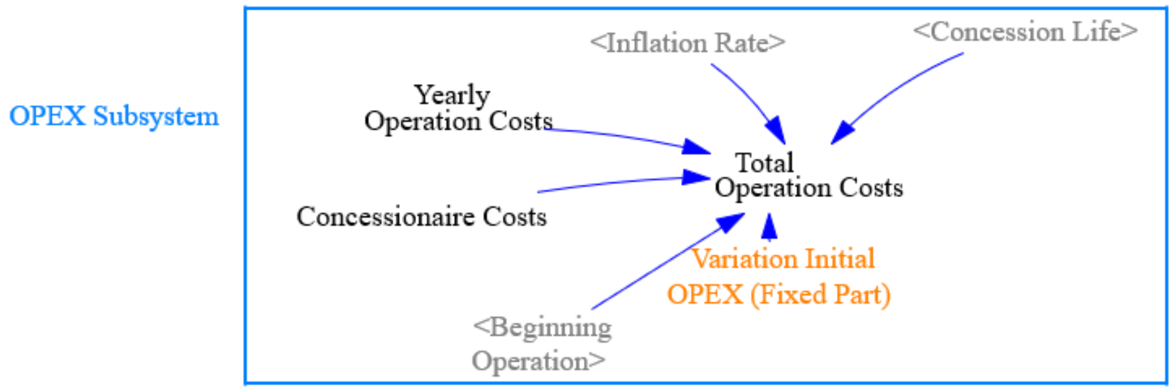

Fig. 3. OPEX Subsystem

The Revenues Subsystem (Fig. 4) includes the concessionaire's revenue derived from the operation of service facilities. The revenues in the SD model rely on the *Tariff* established in the contract for the services provided to supply the *Demand* during the operating period.

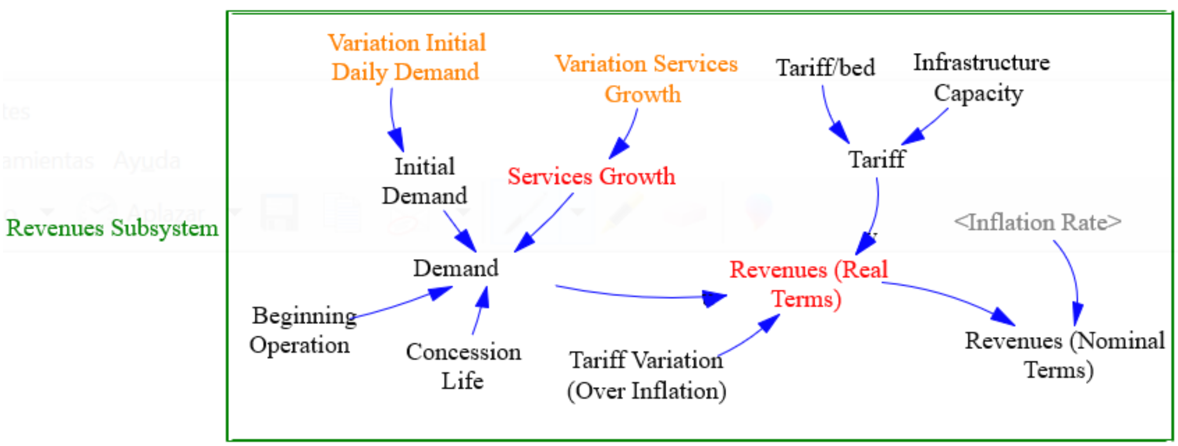

Fig. 4. Revenues Subsystem

The Private Finance & Subsidies Subsystem (Fig. 5) includes the private financing sources (i.e., *Equity* and *Debt*) and the public subsidies. Debt repayment for private debt is based on the SPV assets and cash flows rather than the shareholders' balance sheets. Debt repayment also depends on specific parameters such as *Interest Rate*, *Repayment Period*, and *Grace Period*.

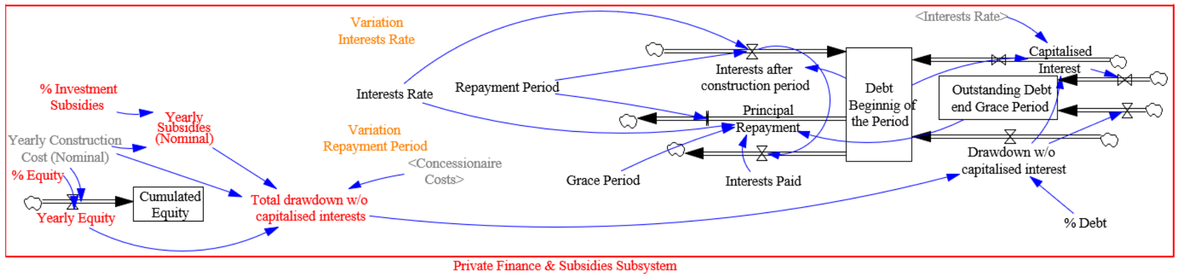

Fig. 5. Private Finance & Subsidies Subsystem

Lastly, all previous subsystems converge on the Cash Flow Subsystem. This subsystem incorporates the *DSCR* as a measure of project bankability. In effect, this ratio should meet the target value on a yearly basis to fulfill the debt provider's financial covenants (Fig. 6).

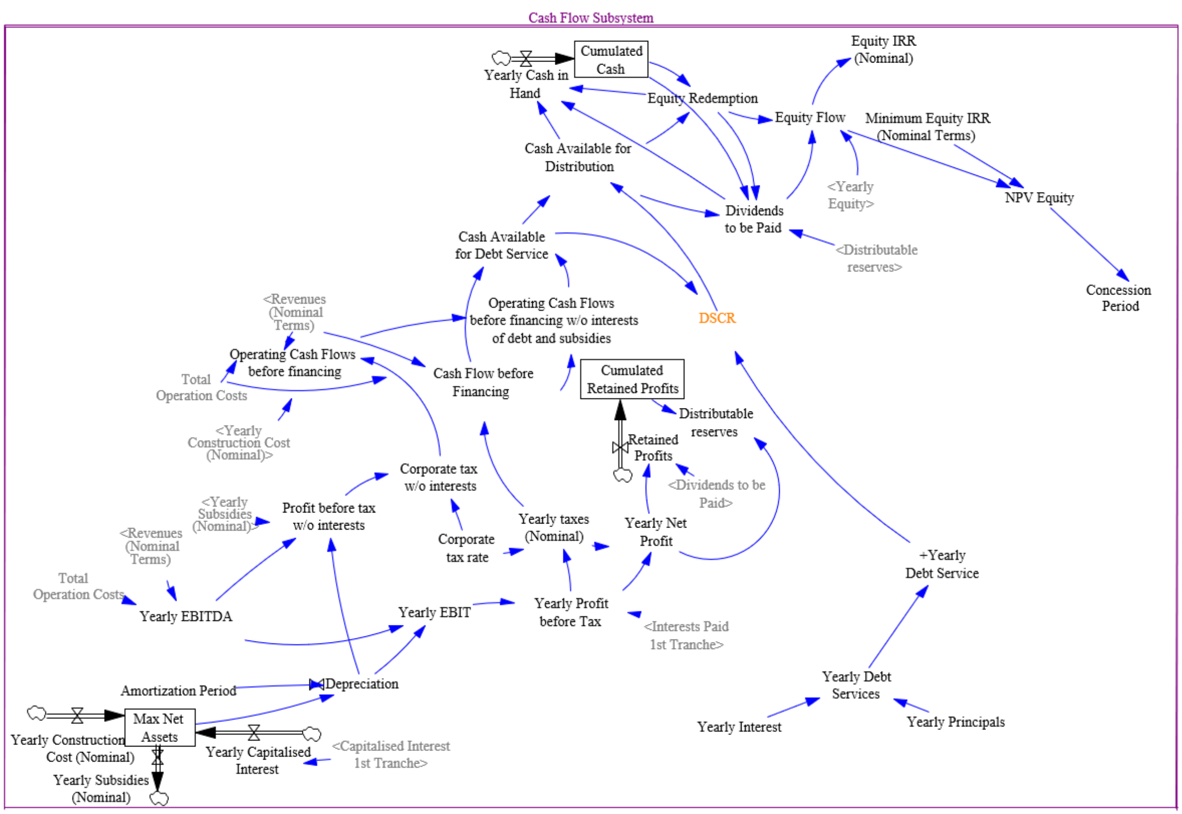

Fig. 6. Cash Flow Subsystem

FINDINGS

Diverse simulations were run to evaluate the extent to which risks and bankability may alter the *Concession Period* in realistic case scenarios. Counterfactual experiments were conducted based on multiple *what-if* scenarios driven by alterations in exogenous parameters. These scenarios serve the purpose of being a tool for public and private entities looking to estimate optimal concession periods for their infrastructure PPP projects. The public sector can use this model to mitigate potential risks that may affect the viability of a project, while private entities can use this model to negotiate an appropriate concession period that accounts for major risks and ensures expected returns are attainable. The model's ability to incorporate both risk and bankability criteria provides a comprehensive approach to PPP project assessment that considers the needs of all stakeholders involved to achieve an optimal concession period.

To accomplish the aforementioned goal, different case-scenario analyses were used to analyze the risks affecting the *Concession Period* and bankability, namely: *Financial Risk, Operation Risk,* and *changes in the Repayment Period*. Base case values of risk parameters were modified to assess their impact on the system outcomes. These outcomes were compared against the baseline scenario, as follows.

Scenario 1 (S1) assessed the impact of *Financial Risk* on the *Concession Period*. The success of any PPP largely depends on financial risks that may affect the target DSCR and, consequently, the debt repayment period. Thus, the DSCR has an inverse relationship with the debt repayment period, whereby a lower DSCR will lead to a longer debt repayment period, and vice versa. This relationship is a crucial factor to consider when determining the optimal concession period for the project, as the concession period must accommodate both the debt repayment period and the grace period for initiating the debt repayment. As a result, a longer debt repayment period will result in a longer concession period, and vice versa.

This scenario considers two key financial risks that can impact the achievement of the target DSCR, *Inflation* and *Interest Rate* (De Marco and Mangano 2013). The *Interest Rate* is a fundamental factor in determining the level of debt the project can support and its internal rate of return, which in turn affects the project's feasibility (Ling and Lim 2007). Since the *Interest Rate* is inherently volatile and can significantly affect a project's financial performance, the baseline scenario incorporates the *Interest Rate* negotiated at the time of the project's financial closure. *Inflation* is another key factor that can adversely impact a project's financial performance. Since infrastructure projects are long-term investments, the value of money can fluctuate significantly over the project's lifespan, triggering an increase in project's costs, reducing the real value of future revenue streams, and negatively affecting the project's financial viability. The objective of S1 is to provide a comprehensive and realistic analysis of the potential impacts financial risks pose to the project's financial performance, based on boundaries used in previous research studies (Feng et al. 2018; Palcic et al. 2018; Zhang et al. 2018).

Table 2. Scenarios Description

		Adjustments		
Scenario	**Parameter**	**Baseline**	**Test Value**	**Units**
S1: Interest Rate (+20%)	Interest Rate	2.5	3	%
S1: Interest Rate (-20%)	Interest Rate	2.5	2	%
S1: Inflation (+20%)	Inflation	4.4	5.3	%
S1: Inflation (-20%)	Inflation	4.4	3.5	%
S2: OPEX (-5%)	Yearly Operation Costs	5,794	5,504	KEuro
S2: OPEX (+5%)	Yearly Operation Costs	5,794	6,083	KEuro
S3: Repayment Period (-20%)	Repayment Period	22	18	Years
S3: Repayment Period (+20%)	Repayment Period	22	26	Years

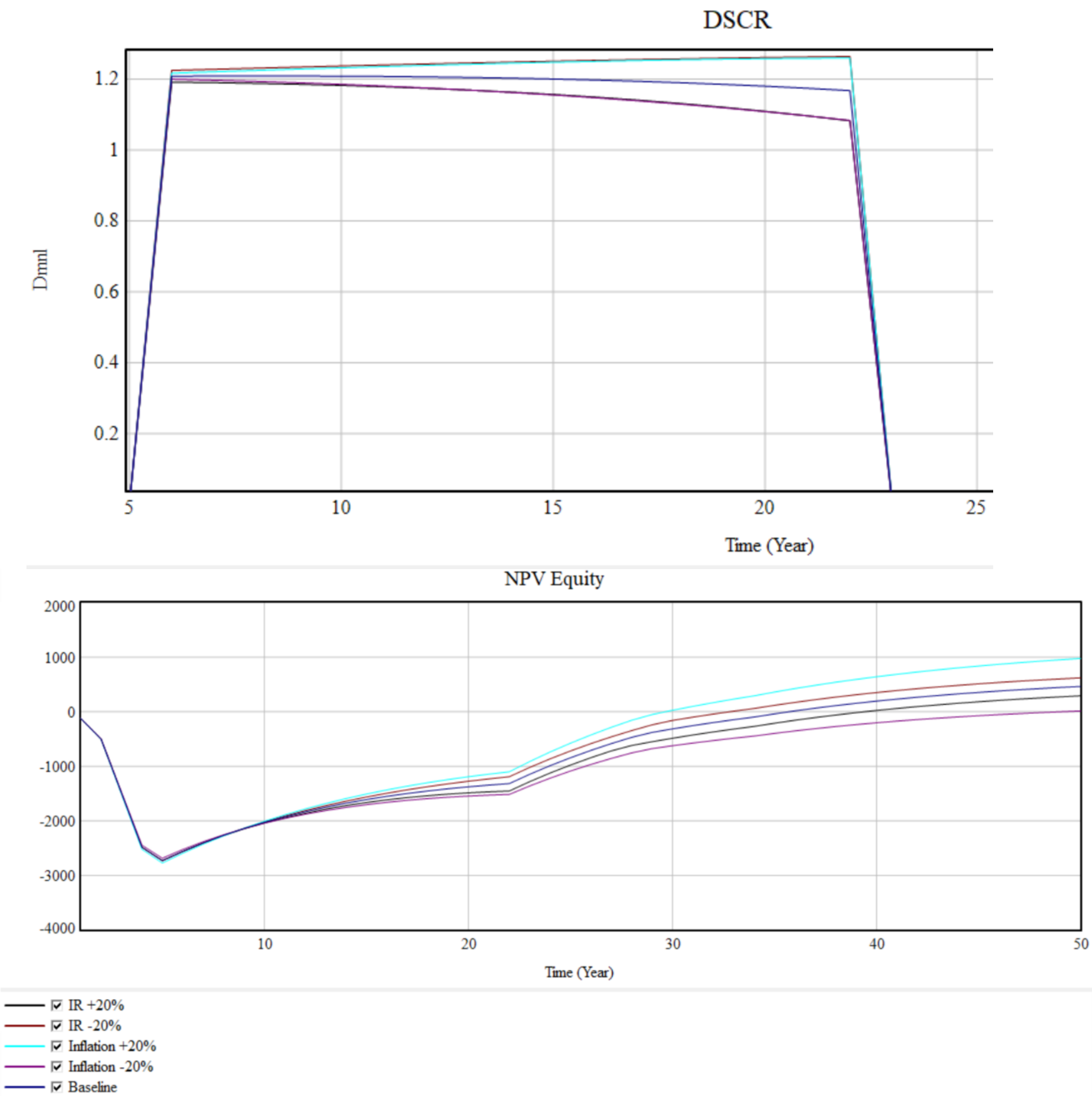

Fig. 7. Effect of Financial Risk on Outcomes

S1 incorporates a change of 0.5% in the *Interest Rate* from the baseline conditions of 2.5% (Table 2), resulting in a range of interest rates between 2% and 3%. The inflation rate also varied between 3.5% to 5.3% from the baseline conditions of 4.4% (Table 2), which is consistent with the range used in the same previous studies (Ng et al. 2007). Figure 7 reveals a heterogeneous impact of financial risks on the *DSCR* and the *Concession Period*. Among the parameters considered for financial risk, the *Interest Rate* constituted the most significant driver of the *DSCR*, with a 0.5% change in the interest rate leading to an over 8% alteration in the DSCR by the end of the repayment period (Table 4). In contrast, *Inflation* has a more significant impact on *Equity's NPV* and thus the *Concession Period*. Remarkably, an *Inflation* increase of only 0.9% is found to be beneficial for reducing the *Concession Period* by five years (from 35 to 30 years), as shown in Table 3. The relationship between *Equity's NPV* and *Concession Period* is based on that the latter represents the length of time during which the SPV is granted the right to operate and maintain the infrastructure asset, as well as collect revenues and profits from its operation to recoup its investments and earn profits from the project according to the pre-established conditions.

Table 3. Equity's NPV Scenarios Simulation Results

T	**OPEX +5%**	**RP -20%**	**Inflation -20%**	**IR +20%**	**Baseline**	**IR -20%**	**Inflation +20%**	**RP +20%**	**OPEX -5%**
23	-2314	-1882	-1359	-1281	-1146	-1020	-912	-481	**26**
24	-2185	-1724	-1217	-1123	-988	-863	-737	-397	213
25	-2067	-1579	-1086	-977	-842	-718	-575	-350	385
26	-1957	-1444	-966	-842	-708	-584	-425	-308	545
27	-1857	-1320	-855	-718	-584	-460	-285	-184	692
28	-1764	-1205	-753	-618	-469	-346	-156	-89	828
29	-1715	-1099	-675	-549	-379	-240	-51	-20	954
30	-1669	-1015	-622	-485	-314	-159	**26**	**45**	1043
31	-1626	-955	-573	-425	-254	-99	99	105	1120
32	-1586	-899	-527	-369	-198	-42	167	161	1192
33	-1548	-846	-485	-317	-146	**11**	231	213	1259
34	-1513	-797	-445	-269	-97	60	291	262	1322
35	-1467	-739	-396	-210	-38	118	361	321	1393
36	-1425	-685	-351	-156	**16**	172	425	375	1459
37	-1386	-635	-309	-106	66	222	485	425	1520
38	-1349	-588	-270	-60	112	269	541	471	1576
39	-1316	-545	-235	-17	155	312	593	514	1629
40	-1284	-506	-202	**23**	195	351	641	554	1677
41	-1255	-469	-172	60	232	388	686	591	1722
42	-1229	-434	-144	94	266	423	728	625	1764
43	-1204	-403	-118	126	298	454	767	657	1802
44	-1181	-373	-95	155	327	484	804	686	1838
45	-1159	-346	-73	183	355	511	838	714	1871
46	-1140	-321	-53	208	380	536	869	739	1902
47	-1121	-297	-34	231	403	560	899	762	1930

48	-1104	-276	-17	253	425	581	926	784	1957
49	-1089	-256	-1	273	445	601	952	804	1981
50	-1074	-237	**14**	292	464	620	975	823	2004

Note: The bold numbers represent the first positive Equity's NPV for each Scenario

Table 4. DSCR Scenarios Simulation Results

T	**RP - 20%**	**OPEX +5%**	**IR +20%**	**Inflation -20%**	**Baseline**	**Inflation +20%**	**IR - 20%**	**OPEX -5%**	**RP +20%**
6	1.00	1.07	1.19	1.20	1.21	1.22	1.22	1.35	1.38
7	0.99	1.06	1.19	1.20	1.21	1.22	1.23	1.35	1.39
8	0.99	1.06	1.19	1.19	1.21	1.22	1.23	1.36	1.40
9	0.98	1.06	1.19	1.19	1.21	1.23	1.23	1.36	1.40
10	0.97	1.05	1.18	1.19	1.21	1.23	1.24	1.36	1.41
11	0.97	1.05	1.18	1.18	1.21	1.24	1.24	1.37	1.41
12	0.96	1.04	1.17	1.17	1.21	1.24	1.24	1.37	1.42
13	0.95	1.04	1.17	1.17	1.20	1.24	1.25	1.37	1.42
14	0.94	1.03	1.16	1.16	1.20	1.24	1.25	1.37	1.42
15	0.93	1.02	1.16	1.16	1.20	1.25	1.25	1.38	1.43
16	0.92	1.02	1.15	1.15	1.20	1.25	1.25	1.38	1.43
17	0.91	1.01	1.14	1.14	1.19	1.25	1.25	1.38	1.43
18	0.89	1.00	1.13	1.13	1.19	1.25	1.26	1.38	1.44
19		0.99	1.12	1.12	1.18	1.26	1.26	1.38	1.44
20		0.98	1.11	1.11	1.18	1.26	1.26	1.38	1.44
21		0.97	1.10	1.10	1.17	1.26	1.26	1.38	1.45
22		0.96	1.08	1.08	1.17	1.26	1.26	1.38	1.45
23									1.45
24									1.45
25									1.45
26									1.45

Scenario 2 (S2) incorporates *OPEX* alterations to analyze their impact on bankability and the *Concession Period* under the premise here is operating risk is entirely allocated to the SPV. The relationship between *OPEX* alterations and the concession period is twofold. On the one hand, a longer concession period provides the private partner with more time to recoup its investments and earn profits from the project. However, a longer concession period also increases the risk exposure. *OPEX* escalation in a healthcare PPP project may stem from failure to comply with regulatory requirements, staffing issues, and lack of proper maintenance, which may affect the overall project's success. When labor or O&M costs increase beyond what was initially forecasted, it could

significantly impact the ongoing operating costs of the project. Additionally, healthcare PPPs are subject to a wide range of regulations and standards, which can be complex and costly to comply with. Thus, an increase in operating costs can result in decreased profitability, reputational damage, and difficulties to meet debt service obligations.

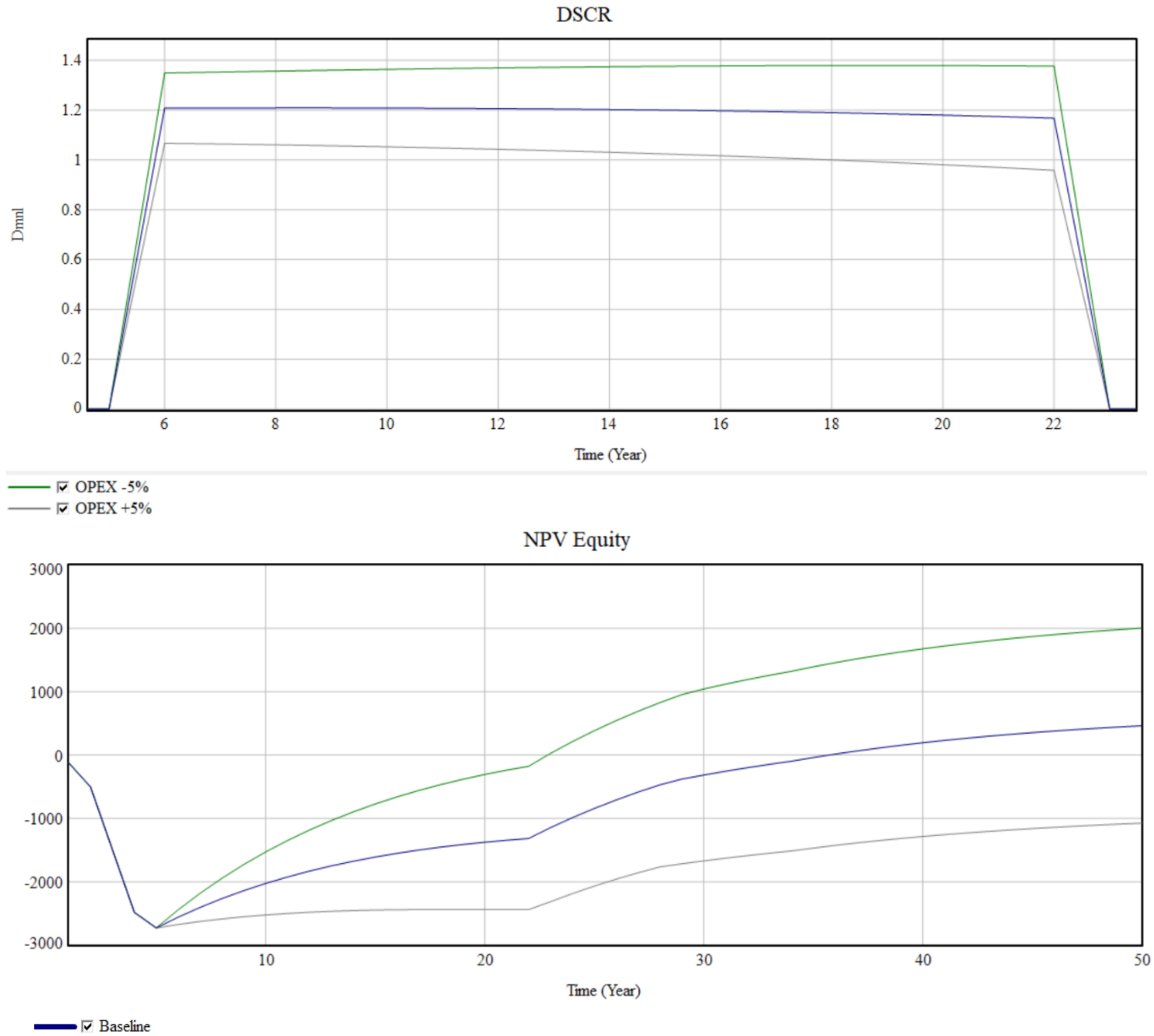

Fig. 8. Effect of Operation Risk on Outcomes

Scenario 3 (S3) incorporates changes in the *Repayment Period* ex-post, which is a strategy that can be used to mitigate financial risk and optimize both bankability and the *Concession Period*. Changes in economic or market conditions can also trigger potential adjustments in the agreed-upon repayment schedule. In effect, adjustments in the repayment period can help to address these risks by extending the timeline for repayment and reducing the immediate financial burden on the private concessionaire. Changes in the repayment period may involve revisiting the terms of the original PPP contract, negotiating new terms with the private concessionaire, and obtaining approval from relevant public authorities. This might also require the involvement of external financial institutions or investors, as changes to the repayment schedule may impact the overall financial structure of the PPP project. This strategy was successfully implemented in projects such as the AP7 Highway in Spain (Cruz and Sarmento 2021).

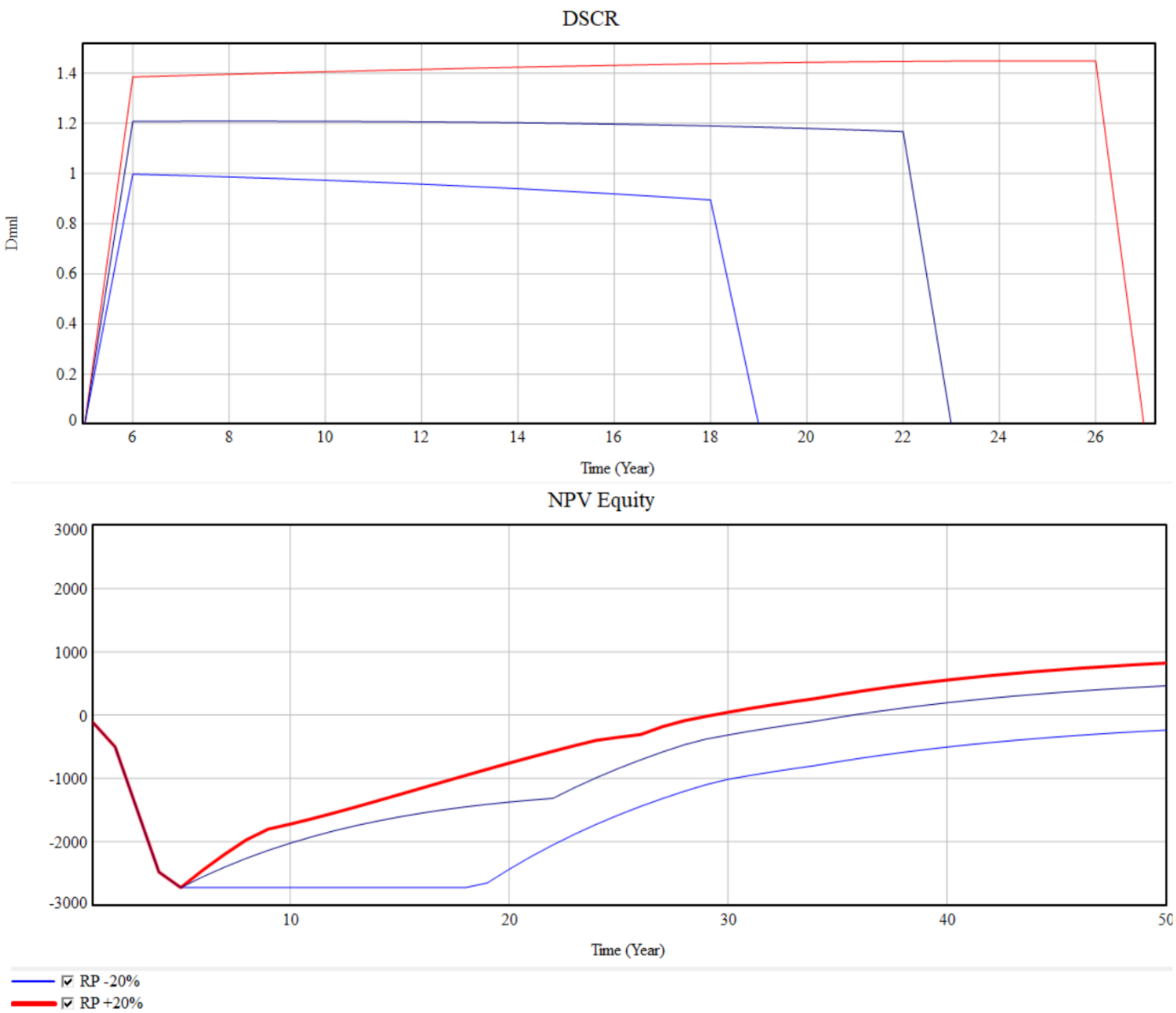

Fig. 9. Effect of Changes in Repayment Period on Outcomes

The comparison between S2 and S3 (Figures 8 and 9) reveals a heterogeneous impact on the *DSCR* and the *Concession Period* derived from *OPEX* and *Repayment Period* alterations. S2 introduces a

5% change in the *Yearly Operation Costs* from the baseline (Table 2), which falls within the range of *OPEX* savings observed in various PPPs (Reis and Sarmento 2017). S3 introduces a change to the *Repayment Period* of 4 years from the baseline (Table 2), which can be suitable for debt providers, as it does not affect the rate of return on the debt. The simulation showed that changes in the *Repayment Period* constitute the most significant driver of the *DSCR*, with a 4-year change in the *Repayment Period* leading to an over 25% change in the *DSCR* by the end of the repayment period (Table 4). In contrast, *OPEX alterations* have a more significant impact on the *Equity's NPV* and thus the *Concession Period*. Remarkably, an *OPEX* reduction of only 5% shortens the *Concession Period* by 12 years (from 35 to 23 years), as shown in Table 3.

DISCUSSION

The SD model proposed in this paper is a powerful tool that can be used by decision makers in the public and private sectors to analyze in an integrated way multiple factors that may affect the PPP concession period. This model offers a comprehensive approach to project assessment by incorporating both risk and bankability criteria. By doing so, it provides stakeholders with a realistic estimate of the optimal concession period that can be achieved, taking into account the potential risks and expected returns associated with the project.

By identifying and modeling the feedback loops related to specific risks, such as financial, operational expenses (OPEX), and debt conditions, the model provides a powerful tool to explore the potential impact of different scenarios on bankability and the concession period. One of the key strengths of the proposed model is its ability to incorporate feedback loops and simulate different case scenarios that illustrate complex interactions between different factors influencing the project's risk profile and the concession period.

The analysis of financial risk demonstrated that high volatility on the *Interest Rate* has a direct detrimental effect on the *DSCR* and a secondary effect on the *Concession Period*. This twofold effect of financial risk on bankability and *Concession Period* is especially relevant because, under project finance schemes, PPPs typically incorporate a variable interest rate to finance the debt portion that is linked to a benchmark or reference interest rate. Moreover, interest rates pose risks of increasing debt service payments, putting pressure on the project's cash flow, and potentially affecting its financial viability. Therefore, project sponsors and lenders must carefully consider the potential risks of variable interest rates, especially under conditions of high volatility. In fact, interest rates have been significantly affected by alterations in macroeconomic conditions driven by the 2008 GFC, the Covid-19 pandemic, and more recently the supply chain and inflation crises (Casady and Baxter 2020). During the 2008 GFC, credit tightened and interest rates for PPPs increased, leading to delays and cancellations of some projects (Loxley 2012). During the Covid-19 pandemic, interest rates for PPPs initially decreased due to central banks implementing monetary policy measures to stabilize the economy and support financial markets. However, as the pandemic continued and economic uncertainty persisted, interest rates for PPPs became more volatile and unpredictable (Castelblanco et al. 2022). More recently, the supply chain and inflation crisis since 2021 have led to increased inflation expectations, resulting in investors demanding higher returns to compensate for the increased risk of inflation (Fyfe 2021). This rise in interest rates has made it more difficult and expensive for PPPs to obtain financing and could potentially impact the viability of some projects.

Conversely, fluctuations in the *Inflation Rate* affect the *Concession Period* more significantly than bankability. A higher *Inflation Rate* has a dual effect on the project's financial performance—it increases the capital and operational expenditures and simultaneously increases the revenues. Interestingly, the simulation demonstrated that a higher *Inflation Rate* is beneficial for the financial performance of PPPs because the overall benefit from higher revenues outweighs the negative impact of higher costs, resulting in a significant improvement in the *Concession Period*, making PPPs more attractive to investors. This finding has important implications for the design and financing of PPPs and underscores the need for project sponsors and investors to carefully consider the potential impact of inflation on project financial performance.

The comparison between scenarios also reveals a heterogeneous impact on the *DSCR* and the *Concession Period* derived from *OPEX* and *Repayment Period* alterations. Specifically, changes in the *Repayment Period* are the most significant driver of the *DSCR*. In contrast, *OPEX* alterations have a more significant impact on the *Equity's NPV* and thus the *Concession Period*. Based on this finding, decision makers should pay close attention to OPEX expenses and develop strategies to reduce these expenses where possible, without compromising the quality of the project or its ongoing maintenance needs to improve the project's financial performance, increase the project's bankability, and make it more attractive to investors.

Lastly, effects of the *Repayment Period* on a PPP's *Concession Period* may offer a potential solution for addressing financial stress when interest rates fluctuate significantly. Previous studies have highlighted the natural risk aversion of lenders who are reluctant to accept low-interest rates without the potential for significant upside (Lenferink et al. 2014; Yescombe and Farquharson 2018). This study builds on these findings by introducing an alternative (increasing the *Repayment Period* and its associated *Concession Period*) that lenders can use to reduce bankruptcy risk without sacrificing profitability. For financing entities, this intervention is particularly valuable, as this parameter is entirely within the control of the lending institutions themselves, providing an added level of flexibility and control. In certain countries, including Portugal, the UK, Colombia, and Chile, there has been a shift away from conventional fixed-term PPP contracts towards flexible-term arrangements (Engel et al. 2020). These contracts feature flexible terms that empower the SPV to receive a predetermined amount of revenue, thereby mitigating demand risk. However, there may be potential barriers to implementing such flexibility in some cases, such as specific constraints on the *Repayment Period* for certain types of debt (e.g., bonds). These barriers can potentially be addressed with the support of the public sector and multilateral financing entities (Yescombe 2014).

CONTRIBUTIONS & IMPLICATIONS

Overall, this study provides a valuable tool to public and private entities looking to estimate optimal concession periods for their infrastructure PPP projects. Public entities can use this SD model to mitigate potential risks that may affect the viability of a project, while private entities can use this model to negotiate an appropriate concession period that accounts for major risks and ensures expected returns are attainable. The model's ability to incorporate both risk and bankability criteria provides a comprehensive approach to PPP project assessment that considers the needs of all stakeholders involved to achieve an optimal concession period.

By identifying and modeling the feedback loops related to specific risks, the model allows decision makers to explore the potential impacts of different scenarios on the PPP bankability and concession period.

The analysis of financial risk revealed that high volatility in the interest rate has a direct detrimental effect on the *DSCR* and an indirect effect on the *Concession Period*, thereby affecting the bankability and viability of the PPP. In this regard, project sponsors and lenders must carefully consider the potential risks associated with variable interest rates, particularly during periods of high volatility, such as those triggered by the 2008 GFC, the Covid-19 pandemic, and the more recent supply chain and inflation crises. The assessment of *Interest Rate* fluctuations on the bankability and viability of PPPs also sheds light on the need to carefully manage and mitigate financial risks in PPPs. Lenders should consider strengthening interest rate hedges and interest rate caps to limit the impact of interest rate fluctuations on project financial performance. Project sponsors may also consider using fixed-rate financing to reduce interest rate risk.

Additionally, this article offers a new perspective on the impact of inflation on PPPs by showing that higher inflation rates could have a positive effect on the financial performance of PPPs. This finding challenges the conventional wisdom that inflation is always detrimental to financial performance, as it tends to increase the cost of capital, capital expenditures, and operational expenditures, and reduce the purchasing power of revenues. More often than not, high inflation is seen as a potential risk factor for PPPs, leading to reduced project profitability, cash flow, and potential financial insolvency. However, a more nuanced understanding of the relationship between inflation and project financial performance demonstrates that while a higher inflation rate does increase the cost of capital, capital expenditures, and operational expenditures, it also has a positive effect on revenues. This positive effect stems from the fact that many PPP projects have revenue streams that are indexed to inflation. The effect of this revenue increase is more significant than the effect of higher costs, resulting in a significant reduction in the *Concession Period.* Policymakers could use this finding to encourage the use of PPPs for infrastructure development, particularly in environments with high inflation rates.

This study also expands on the current literature by providing new insights regarding the impact of *OPEX* and *Repayment Period* alterations on the PPP concession period. The study shows that while both *OPEX* and *Repayment Period* alterations have an impact on bankability and the *Concession Period* in healthcare PPPs, the *Repayment Period* is the most significant driver of the *DSCR*, with changes to this variable having a greater effect than financial risks and OPEX alterations. By highlighting the importance of the *Repayment Period* and its potential impact on the bankability of PPP projects, this study provides decision makers with valuable insights about how they can optimize project performance and ensure long-term financial sustainability.

Conversely, the fact the concession periods of healthcare PPPs are especially sensitive to *OPEX* alterations should motivate concessionaires to prioritize strategies for minimizing operational costs, such as improving energy efficiency, waste management, asset management, and outsourcing.

Moreover, the model contributes to the broader academic discussion on infrastructure project financing, emphasizing the importance of taking a systemic approach to understanding and managing risks. By scrutinizing feedback loops associated with financial risk, OPEX, and debt conditions, the model presents a holistic understanding of the intricate interplay between these factors and the project's risk profile. Two feedback loops exhibit the coexisting positive and negative effects of financial risk on the concession period, while the remaining loops explore the simultaneous reinforcing and balancing effects of OPEX risk and the repayment period on the concession period. Among these coexisting opposite behaviors, this model demonstrates the dominant loops that exert the greatest influence on the behavior of the concession period and bankability.

LIMITATIONS AND FUTURE RESEARCH

Although this study offers multiple contributions to the current literature, the SD model can only help determine the optimal concession period at the bidding or negotiation stage of healthcare PPP projects. Thus, future research should continue to advance our understanding of PPP dynamic concession period models to explore how these can become accurate models to resiliently respond to risks and changes during the lifecycle of the PPP project.

Furthermore, this model focused only on risks affecting a project's whole lifecycle. However, it may be helpful to track how the effects of inflation differ across different stages of the PPP lifecycle. Because PPP concession periods often last for several decades, it is essential to develop effective risk management strategies in the short-, middle-, and long-term. This could involve investigating the use of various financial instruments, such as inflation-linked bonds, swaps, or other inflation-protected assets, to hedge against inflation risks. Secondly, there may be other alternative risk management strategies that were not part of the scope of this study that could be explored in future research, such as revenue-sharing agreements or other innovative financing models, that could help PPPs better manage their risk exposure.

A third area of future research is to delve deeper into other infrastructure types or regions that are most vulnerable to financial and macroeconomic risks. By focusing on these specific contexts, researchers can develop more effective risk management strategies to mitigate these risks. This could also include exploring the potential impact of political and regulatory risks on PPP performance, particularly in emerging markets where these risks may be more pronounced. Finally, while this model was validated only using healthcare PPP projects, future research could expand this model's application to other sectors to gain insights from comparative analysis. This might provide a more comprehensive understanding of the impact of risks on the concession period across different sectors and geographic regions.

CONCLUSION

The proposed SD model offers a powerful tool to help decision makers estimate, bid, and negotiate a realistic concession period for infrastructure PPP projects, taking into account both risk and bankability criteria. By identifying and modeling feedback loops related to financial, OPEX, and debt conditions risks, the model provides a comprehensive understanding of the complex interactions between different factors that influence the project's risk profile and its optimal concession period.

The analysis of financial risk demonstrated the direct and indirect effects of high volatility on interest rates and the potential benefits of a higher inflation rate on a project's financial performance. The model's results also showed that high volatility in interest rates has a direct and detrimental effect on a project's DSCR and a secondary effect on the concession period. The recent global financial crisis, Covid-19 pandemic, and inflation crises have significantly affected interest rates, making it more difficult and expensive for PPPs to obtain financing, which could potentially impact the viability of some projects. Conversely, high inflation rates have a marked positive impact on the concession period, as the benefits from increased revenues outweigh the negative impacts of higher costs.

The scenario analyses further demonstrate heterogeneous impacts on *DSCR* and the *Concession Period* from *OPEX* and *Repayment Period* changes. *Repayment Period* modifications are the main driver of the *DSCR*, while *OPEX* changes have a greater effect on the *Concession Period*. Thus, decision makers must focus on OPEX expenses and devise strategies to decrease these costs without compromising project quality or maintenance requirements. The *Repayment Period's* impact on PPP's *Concession Period* offers a potential solution for financial stress during significant interest rate fluctuations. This study presents an alternative to traditional interest rate interventions, which can reduce bankruptcy risk and avoid increasing the concession period without sacrificing profitability.

This intervention is particularly valuable for financing entities, as it provides an added level of flexibility and control. However, specific constraints on the *Repayment Period* for certain types of debt, such as bonds, may limit the implementation of this intervention. However, this can be counteracted with support from public sector and multilateral financing entities.

Finally, the proposed model has relevant theoretical and practical implications. First, public entities can identify and mitigate risks, while private entities can assess risks and returns to make informed investment decisions. This should help in formulating effective redesign policies to achieve optimal concession periods. Second, by identifying and modeling feedback loops related to specific risks, the model permits decision makers to explore the potential impacts of various scenarios on the concession period through a systemic approach to risk management. Third, lenders and project sponsors should use this model to evaluate the potential impact of variable interest rates on the concession period and bankability during periods of high volatility, such as the recent supply chain and inflation crises. Lenders may consider assessing the impact of interest rate hedges and caps to limit the impact of interest rate fluctuations, while project sponsors may evaluate the impact of fixed-rate financing on the concession period. Moreover, this article challenges conventional wisdom that inflation is always detrimental to the financial performance of PPPs, showing that a higher inflation rate can have a positive effect on project performance. This finding could encourage the use of PPPs for infrastructure development in high-inflation environments. Lastly, this study revealed that the *Repayment Period* is the most significant driver of the *DSCR*, while *OPEX* alterations are the most significant driver of the *Concession Period*. Therefore, concessionaires should prioritize strategies for minimizing operational costs, such as improving energy efficiency, waste management, asset management, and outsourcing.

DATA AVAILABILITY STATEMENT

Some or all data, models, or codes that support the findings of this study are available from the corresponding author upon request.

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