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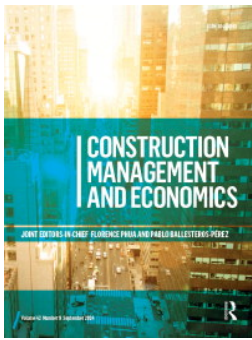
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## Financial system dynamics model for multidimensional flexibility in toll road PPPs: a life-cycle analysis

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### ABSTRACT

Although scholars have developed simulation models and analyzed bankability criteria in numerous papers to enhance the financial outcomes of Public-Private Partnerships (PPPs), the intersection between both fields considering alternatives to assess the financial impact of flexibility in both scope and financing, remains underdeveloped. To address this gap, this paper introduces a financial model that assesses the financial impact of suitable life-cycle flexibility alternatives while coexisting with revenue performance alterations in each project phase within toll road PPPs. This model serves as a tool to gain insight into the planning of strategic actions to implement flexibility in both scope and financing. Based on system dynamics and validated using financial data from two toll road PPPs in India and East Europe, simulation results suggest that two key drivers (capital expenditures and debt repayment period) have the greatest influence on financial performance. Findings support the implementation of flexible scopes to effectively address the most influential exogenous factor impacting the financial performance of PPPs, namely traffic shortfalls. This model provides a suitable tool for assessing the life-cycle economic sustainability of PPPs in uncertain and complex environments.

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### KEYWORDS



System dynamics; project finance; life-cycle analysis; traffic; CAPEX; OPEX; debt

### Introduction

Besides the potential strengths of Public-Private Partnerships (PPPs), the success of this kind of delivery methodology relies significantly on addressing uncertainties across the project's life-cycle and avoiding the diminishment of the private sector's expected financial returns (Damjanovic *et al.* 2016, Nguyen 2017). Uncertainties associated with debt-related conditions, construction expenditures, and operation costs in PPP projects can potentially threaten the private sector's financial expectations and jeopardize projects' bankability (i.e. lenders' willingness to finance PPPs after due examination of their related returns and risks) (Nguyen 2017). These conditions are particularly relevant for toll road PPPs, as they incorporate traffic demand as an additional uncertainty for revenues throughout their life-cycle (Burke and Demirag 2015, Castelblanco *et al.* 2023a). In fact, different PPP toll projects have been met with financial distress since the traffic levels were significantly lower than that

forecasted for the projects (Liu *et al.* 2017) and public authorities may offer forms of guarantee to relieve exogenous risks to make the project more attractive for private investors (Brandao and Saraiva 2008, Zapata Quimbayo *et al.* 2019).

In this context, the economic sustainability of toll road PPPs relies significantly on the private sector's financial performance when uncertainties take place (Narbaev 2022). For toll road PPPs, private partners must comprehensively understand the financial implications of diverse and complex scenarios to prioritize suitable strategies for optimizing life-cycle revenues and expenditures (Yuan *et al.* 2019, Ortiz-Mendez *et al.* 2023, Castelblanco *et al.* 2023b). To do so, the private sector's decision-makers must be aware of the relations between sources of payment (e.g. user fees), financing variables (e.g. interest rates and repayment periods), and investment parameters (e.g. capital expenditures and operational expenses), in conjunction with their implications for PPP life-cycle costs (Damjanovic *et al.* 2016).

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The existing literature offers a range of simulation models and bankability criteria to evaluate the financial outcomes of PPPs (Xiong and Zhang 2014, Xiong *et al.* 2016, Ullah *et al.* 2018, Bae *et al.* 2019, Shalaby and Hassanein 2019, Jin *et al.* 2020). However, there is a critical research gap in understanding the intersection between these models and the identification of strategies to implement flexibility comprehensively.

Most previous financial models in the PPP context have focused primarily on establishing concession parameters before tendering or dealing with renegotiations during the operation phase. This approach neglects the need for a holistic and longitudinal that encompasses all stages of the PPP life-cycle. For example, Ullah *et al.* (2018) developed a financial model that overlooked important factors such as debt and financial costs, limiting its applicability to determining concession periods before procurement. Similarly, Yuan *et al.* (2019) concentrated solely on modeling the concession period and public subsidies without considering bankability aspects or the impact of uncertainty effects on construction and operational costs. Other models have predominantly focused on renegotiations during the operation phase (Xiong and Zhang 2014, Xiong *et al.* 2016, Bae *et al.* 2019, Shalaby and Hassanein 2019, Jin *et al.* 2020).

Financial outcomes of PPP projects are often far from financial modeling estimations, and there have been numerous instances of PPPs failing on a global scale due to the established financial models falling short in covering operational costs and ensuring profitability. Such failures have led to financial losses for private equity investors and, in some cases, have had adverse repercussions for debt financiers, including bondholders and governmental bodies. An illustrative case in point is the State Highway 130 project in Texas, USA, which ultimately declared bankruptcy when the project was unable to guarantee a minimum bankability criteria. Consequently, the federal government was compelled to step in and acquire an equity stake in the new toll road operator, resulting in reduced government exposure to debt and facilitating cash payments. Nonetheless, the repayment status of the federal government's extended loan remains uncertain (Congress of the United States 2020). Another notable example is the South Bay Expressway in San Diego, California, USA, where the private partner filed for bankruptcy (Gifford *et al.* 2023). Subsequently, the bankruptcy court introduced a revised financing and ownership structure to completely redefine the original financial model, incorporating a blend of secured debt and equity, which

amounted to only 58% of the initial investment (Jensen 2011).

To bridge this gap, this study introduces a novel financial model that evaluates the financial impact of flexibility in scope and financing throughout the different phases of toll road PPPs. By integrating concepts from life-cycle cost assessment (LCCA), system thinking, and project finance, this model quantitatively assesses the potential cost and revenue performance alterations. It aims to offer strategies to implement flexibility in scope and financing in toll road PPPs. The validity and effectiveness of the model are demonstrated through its application to two distinct toll road PPP projects in India and Eastern Europe.

While extant literature has emphasized the impact of exogenous determinants on the financial performance of PPPs and the frequency of renegotiations (Cruz and Sarmiento 2021), this study takes a step further by assessing the financial life-cycle impact of alterations to these parameters. Previous research has extensively analyzed the relevance of traffic to the financial performance of road PPPs from a general perspective (Flyvbjerg *et al.* 2007, Vassallo *et al.* 2012, Carpintero *et al.* 2013, Cruz *et al.* 2014). In contrast, this paper quantitatively evaluates the effect of demand alterations on PPP financial performance, considering important exogenous parameters such as debt interest rate and CAPEX overruns resulting from external factors.

Overall, the proposed model is a tool for gaining insight into designing real-time strategic actions when facing potential underperformances during each of the life-cycle PPP phases, by decoding multiple interacting feedback processes to self-correct or self-reinforce specific behaviors within complex systems.

The structure of this paper is as follows: Initially, a literature review on project finance and SD models applied to toll road PPPs is presented. The methodology for the construction of the model and the validation process are outlined. Next, the results are analyzed and discussed, with a focus on practical and theoretical implications. Finally, the paper concludes with a summary of findings and suggestions for future research.

## Literature review

A comprehensive literature review was conducted to establish the relationship between financial drivers and their corresponding mathematical expressions. This systematic analysis aimed to provide a strong theoretical and mathematical foundation for the Causal Loop Diagram (CLD) and the SD Stock and Flow Diagram (SFD) presented in this study.

**Table 1.** Search strategy.

Steps	Description
Keywords and Boolean expression	(ALL (“concession” OR “PFI” OR “private finance initiative” OR “toll road” OR “build operate transfer” OR BOT OR “public private partnership” OR “P3” OR “PPP”) AND (LCCA OR “life-cycle cost assessment” OR “life-cycle analysis”) AND (“project finance” OR financing OR capital OR traffic OR equity OR subsidy))
Timespan	2008-2020
Databases	Scopus

As shown in Table 1, the search encompassed terms related to PPPs, LCCA, and project finance. The search was focused on the *Scopus* database, covering the period between 2008 and 2022. Scopus was chosen as it is widely regarded as one of the most comprehensive bibliometric databases for scientific and technical peer-reviewed literature (Lagorio *et al.*, 2022). The selected timespan aimed to consider publications after the global financial crisis in 2008, as researchers have emphasized the incorporation of impacts from unprecedented uncertainty on financial drivers during this period (Reis and Sarmiento 2019). The search strategy resulted in 290 publications. Unrelated research areas were excluded resulting in the removal of 229 publications, leaving 61. Finally, a screening process was conducted by reviewing the titles and abstracts to remove manuscripts that were unrelated to the goal of this research, resulting in a final selection of 40 relevant publications. These included case studies, financial models, and theoretical approaches.

This section is organized into two parts, each addressing a specific aspect of the literature related to toll road PPPs. First, it examines the use of project finance in toll road PPPs, exploring the financial aspects involved, as well as their payment and funding sources. Second, it provides an overview of the financial models commonly employed in PPPs, including LCCA as a tool for evaluating of long-term cost-effectiveness of infrastructure projects.

### **Toll road PPPs through the project finance lens**

Project finance constitutes the financing mechanism established for PPP infrastructure projects worldwide (Yescombe and Farquharson 2018, Salazar *et al.* 2024). Under a project finance mechanism, a legally independent project company (i.e. concessionaire), is created to finance the required investment in a single-purpose capital asset (i.e. PPP project) (Higham *et al.* 2017). This project company is financed with equity from sponsoring firms and nonrecourse debt within the concession period (Weber *et al.* 2016, El Kawam *et al.* 2024). Under

project finance principles, the investment return relies on PPP revenues to generate cash flow during the concession period (Higuchi 2019, Khallaf *et al.* 2024).

Based on the payment mechanisms, there are two main alternative road PPP models, namely, service-fee and usage-based payments. A service-fee road PPP establishes its payment source in the public sector based on the operational availability of the infrastructure during the life-cycle (i.e. availability payments) (Yescombe and Farquharson 2018). Conversely, a usage-based payment PPP relies on user payments (e.g. toll roads) (Yescombe and Farquharson 2018). The increase in fiscal pressure and public budget constraints worldwide has led to a growth in the toll road as the preferred type of PPPs for developing highways in several developing and developed economies (Carpintero *et al.* 2015).

Toll roads' financial structure relies on the project's funding sources (i.e. user and government payments) and financing sources (i.e. equity and debt). Consequently, a financial structure based on project finance principles should be able to assess the cash flows required for guaranteeing CAPEX, OPEX, financial repayments, and equity return at a concessionaire's rate of return, under pre-established risk allocation conditions (Weber *et al.* 2016, Higham *et al.* 2017, Higuchi 2019). Toll road projects require high leverage through long-term debt financing to access a larger pool of funds required for capital-intensive projects (Sanchez Soliño *et al.*, 2018). This approach reduces the reliance on substantial equity contributions and results in a lower cost of capital compared to relying solely on equity financing to enhance user fees' (Yescombe and Farquharson 2018).

The financial performance of PPPs is influenced by various factors, including capital structure (De Marco and Mangano 2017), unforeseen events (Domingues and Zlatkovic, 2015), traffic flow volumes (Akomea-Frimpong *et al.* 2021), traffic forecasts' inaccuracies (Villalba-Romero and Liyanage 2016), and stakeholder alignment (Verweij and van Meerkerk, 2021). To improve PPP performance, it is crucial to adopt holistic approaches that address the complex interplay of socio-technical systems (Warsen *et al.*, 2018). By considering these factors and adopting a comprehensive perspective, decision-makers can enhance the overall financial outcomes of PPP projects.

### **Financial models and LCCA in PPPs**

Financial models are suitable tools for assessing projects' financial performance considering uncertainty

and the stakeholders' interests (Biziorek *et al.* 2023, Castelblanco and Guevara 2024, Ottaviani *et al.* 2024). The need for PPP financial models has increased as the investment in this project delivery strengthened during the last three decades especially after global crises to address unforeseen events (Kumar *et al.* 2021).

Traditionally, PPP financial models have focused on specific project phases, lacking a life-cycle perspective (Mohamad *et al.*, 2018). This study addresses this gap by quantitatively analyzing suitable alternatives for rebalancing financial underperformance at any PPP stage, considering bankability and uncertainty. Common financial models concentrate on the feasibility stage, determining the concession period, capital structure, or revenue model (Hanaoka and Palapus 2012, Khanzadi *et al.* 2012, Ma *et al.* 2018). Other focus on the operation phase, tackling ex-post renegotiations due to private sector bankruptcy or government-led modifications (Gong and Tian 2012, Xiong and Zhang 2014). By adopting a comprehensive approach, this research fills the void, enabling decision-makers to effectively manage financial underperformance throughout the entire PPP lifecycle.

For the feasibility stage of PPPs, researchers have proposed financial models to establish an optimal concession period. Several models have been focused on determining optimal concession periods based on approaches such as bargaining game theory (Ma *et al.* 2018), real options (Ma *et al.* 2018), Monte Carlo simulation (Hanaoka and Palapus 2012), and fuzzy logic (Khanzadi *et al.* 2012). Nevertheless, these models only establish the optimal concession period rather than providing decision-makers with alternatives to tackle uncertainties once the procurement phase has finished.

For the implementation and operation phases of toll roads, previous financial models have been focused on renegotiations. These models have been focused on assessing renegotiation alternatives in PPPs based on approaches such as net present value (Bae *et al.* 2019, Shalaby and Hassanein 2019), time series analysis (Xiong and Zhang 2014), game theory (Jin *et al.* 2020), and real options (Xiong and Zhang 2016). However, these models are focused only on assessing alternatives by increasing the public subsidies or the concession period, which results in detrimental effects for the public sector or the users.

## Research methodology

This study develops a SD model for assessing suitable alternatives for implementing flexibility in scope and

financing while considering potential cost and revenue performance alterations under a life-cycle perspective in toll roads. SD is used to expose the concurrent feedback loops that drive the concessionaire's equity flow throughout its lifecycle. An analysis of the potential concessionaire's interventions was developed to improve the understanding of the main drivers of flexibility in scope and financing that affect PPPs' financial performance by conducting counterfactual experiments.

This study developed a five-stage methodology as shown in Figure 1. A comprehensive literature review focused on project finance allowed for the development of the CLD, the SFD, and the quantitative model equations. Once the formulation of the model was completed, the model was assessed twofold, based on real case study data from India and East Europe. Finally, an analysis of the concessionaire's interventions was conducted to propose specific actions to address PPPs' financial underperformance.

## Data sources

Once the scientific literature was analyzed, one of the most significant challenges for the data collection was obtaining financial data from real PPP projects. This is not a minor issue given the lack of transparency of financial data of PPP projects evidenced by several academics and practitioners (Agyenim-Boateng *et al.* 2017, Guevara *et al.* 2020). The authors gathered financial data from two real PPP projects, the road to Kolkata NH-34 (Yog and Eppler 2017) and a BOT toll road in Eastern Europe (PPIAF 2008). These data sets were chosen because they included consistent data regarding the project's debt, and the concessionaire's equity cash flow as a reference for the model outputs, so as the complete input parameters required for the model and improving model formulation for including increasing debt tranches, vehicles categories, and the number of tolls, among others. A twofold validation process contributed to strengthening the model's reliability, considering the different configurations of each project.

The Indian project (Project 1) has a concession period of 25 years including 3 years of the construction phase (Table 2) (Yog and Eppler 2017). This road had an initial overall traffic volume of almost 15,000 vehicles per day distributed in two tolls, each including six categories of vehicles. The CAPEX of US 425 million was financed by 18% with private equity, 32% with public subsidies, and the remaining 50% with loans.

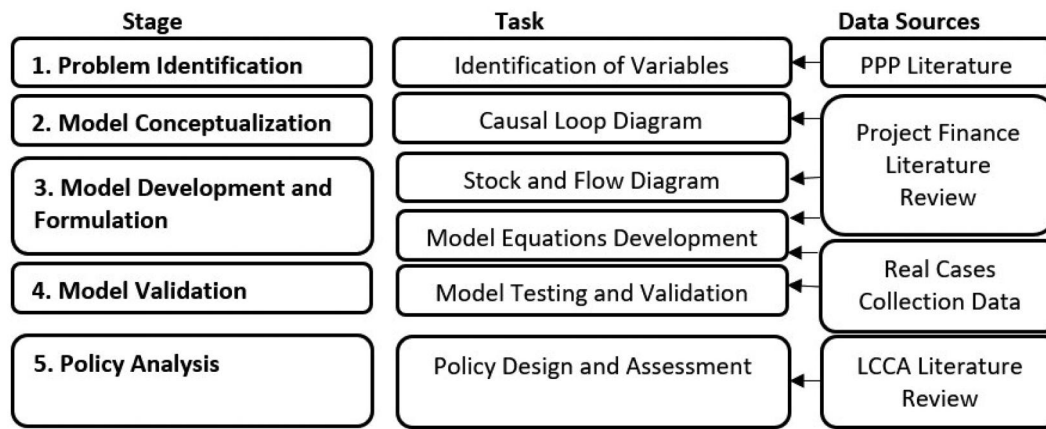


Figure 1. Simulation model's stages, activities, and data sources.

Table 2. Exogeneous parameters.

Parameter	Project 1	Project 2	Units
Concession Life	25	50	years
Highway Length	200	125	km
Traffic Growth	[3.2–7.2]	3	%
Initial Daily Traffic	[0.005–2.585]	5	k Vehicles/day
Toll rate/km	[0.011–0.079]	[0.13–0.25]	USD/km
Construction Period	3	4	years
Construction Cost per km	2,125	5,500	kUSD
Interest Rates	10.75	[4–5]	%
Repayment Period	18	[10–20]	years
Grace Period 1st Tranche	5	[5–6]	years
Heavy Maintenance Period	5	8	/years
Variable Operation Costs	-	[0–0.6]	USD/Veh
IRR of the Equity	18	16	%

The Eastern Europe project (Project 2) has a concession period of 50 years including 4 years in the construction phase (Table 2) (PPIAF 2008). This project has a debt structure more complex than the Indian project because the debt is composed of three different tranches each with different interest rates, grace periods, and repayment periods. Conversely, the traffic structure of this project is simpler than the Indian project because there are only two categories of vehicles in one toll, whose initial overall traffic volume is 10,000 vehicles per day. This PPP project does not consider public subsidies; consequently, the CAPEX of US 687.5 million was financed 10% with private equity and the remaining 90% with loans.

### Simulation model definition

To propose suitable alternatives for addressing financial underperformance, the financial model proposed in this study employs a simulation approach for revealing the complex relations among the most significant drivers of the concessionaire's equity flow, based on an LCCA perspective. This approach allows modeling and simulating of this system to obtain

scenarios that feed redesign concessionaire's interventions into PPP programs.

The simulation model examines the financial performance of the toll road considering the benefits, pre-operative costs, depreciated costs, financial, and operation and maintenance (O&M) costs to assess alternatives for re-equilibrate the concessionaire's equity flow during the PPP life-cycle under potential underperformance scenarios. The LCCA approach allows the concessionaire to assess the financial implications of multiple scenarios to define suitable strategies for optimizing their financial returns. From the perspective of the private sector, the concessionaire's equity flow can be written mathematically in the following form (Sánchez-Silva and Klutke 2016):

$$Z(\mathbf{p}) = \sum_{t=0}^{ts} \frac{B(\mathbf{p}) - CO(\mathbf{p}) - CL(\mathbf{p})}{(1 + IRR)^t} \quad (1)$$

Eq. (1) defines the concessionaire's equity flow objective function as a function of the benefits, costs, and the internal rate of return during the concession life-cycle. The term  $B(\mathbf{p})$  is equivalent to all the benefits expected from the existence of the project. The term  $CO(\mathbf{p})$  indicates the CAPEX (i.e. planning, designing, and construction) and  $CL(\mathbf{p})$  is equivalent to all the financial and OPEX costs. The vector parameters  $\mathbf{p}$  represent the decision variables,  $ts$  is equivalent to the project lifetime (i.e. concession period), and IRR the concessionaire's indicates the internal rate of return.

From the perspective of the concessionaire, the decision objective is to reach a non-negative  $Z(\mathbf{p})$  at the end of the concession period. Moreover, to calculate the benefits expected  $[B(\mathbf{p})]$ , the CAPEX  $[CO(\mathbf{p})]$ , and the Financial & OPEX costs  $[CL(\mathbf{p})]$ , the model comprehends more than 120 equations.

The financial model relies on several exogenous parameters including general, toll, traffic, CAPEX, debt,



which aims to alleviate the pressure on the cash flow during the initial operation years. Alternatively, in **B4** the *Concessionaire's Effort for Debt Renegotiation* may result in a lower *Interest Rate* (Yescombe and Farquharson 2018), which reduces *Debt Service*. In either case, the yearly *Financial Cost and Taxes* drop, and, consequently; the yearly *Free Cash Flow to Equity* escalates. Extant literature establishes that when a PPP is under a significant financial underperformance (i.e. high *Net Equity Discrepancy*), the concessionaire invests increasing efforts in renegotiating debt conditions to reduce *Interests* to be paid during the life cycle (Demirag *et al.* 2015). The lenders may be willing to decrease the *Interest Rate* for PPPs under significant financial stress in **B2** to avoid the project's bankruptcy which may constitute a higher detrimental aftermath (Yescombe and Farquharson 2018). Alternatively, under a floating interest rate scheme, projects with no significant financial stress (i.e. low *Net Equity Discrepancy*) may face an increasing *Interest Rate* according to updated current-market rates (Zhang 2005).

**R1** represents the traditional support from the public sector through increasing subsidies to compensate for financial underperformances out of the risk allocated to the private partner. Moreover, **R1** depicts the undesirable behavior of renegotiations triggered by CAPEX increases (De Marco and Narbaev 2021, Marcellino *et al.* 2023). This kind of renegotiation looks for higher *Subsidies* to compensate and even, in extreme cases, exceed the CAPEX increases. This undesirable behavior is related to the unbalanced profit pool syndrome, which refers to a PPP profit pool skewed to the construction contract returns in the short term (Ho *et al.* 2015). Given the significant financial leverage in project finance projects, PPP promoters may prioritize short-term construction returns.

### Model components

Based on the causal model shown previously, an SFD was developed in Vensim® DSS7.3.5 (Figure 3). Four main components are nested within the model influencing the *Free Cash Flow to Equity* according to eq. (1). The *benefits component* increases the *Free Cash Flow to Equity* according to the payment and financing sources. The *CAPEX component* depletes the *Free Cash Flow to Equity* during the construction period according to the planning, designing, and construction costs. The *financial costs and taxes component* reduces the *Free Cash Flow to Equity* according to the debt costs (including different debt tranches) and the taxes

(including depreciation). The last is the *OPEX component* that diminishes the *Free Cash Flow to Equity* according to the fixed and variable operating costs.

### Model validation

Despite the complexity of the financial model, it is, like all the models, a simplification of reality. To gain confidence regarding the model's usefulness, the model was validated based on several confidence tests recommended such as behavior reproduction (accuracy of the model in replicating the real system's behavior), sensitivity analysis (effect of parameters' changes on the model's outputs), integration error (accuracy of the model's numerical solution), extreme conditions (behavior of the model under extreme inputs), parameter assessment (consistency of parameters with the real system), dimensional consistency (consistent units of the model's variables), structure assessment (internal consistency of the model's structure), and boundary adequacy (validity of the model's boundaries and assumptions) (Sterman 2000). The sensitivity analysis is carried out to accurately evaluate the impact of changes on a set of input variables following different statistical distributions. In this way, the robustness of the model is evaluated and, at the same time, the uncertainty issue is considered (Rafew and Raziful, 2023). Behavior reproduction was focused on both stocks of the system –*Free Cash Flow to Equity* and *Debt* – in nominal terms for testing if the model reproduces the behavior of the real system.

### Results

This section highlights the SD model results, focusing on evaluating suitable alternatives for addressing financial underperformance in toll road PPPs by considering potential cost and revenue alterations throughout the project phases. A comprehensive analysis of the SD model was conducted to understand the dynamics of the diffusion process and identify critical driving factors for PPP financial performance, while also assessing the robustness of the model. Figures 6–10 present a sensitivity analysis, showcasing how output values change when input parameters vary.

To assess the effectiveness of balancing loops identified in the SD model in addressing financial underperformance in realistic scenarios, multiple simulations were performed. Counterfactual experiments were conducted to explore “*what-if*” scenarios from a life-cycle perspective.

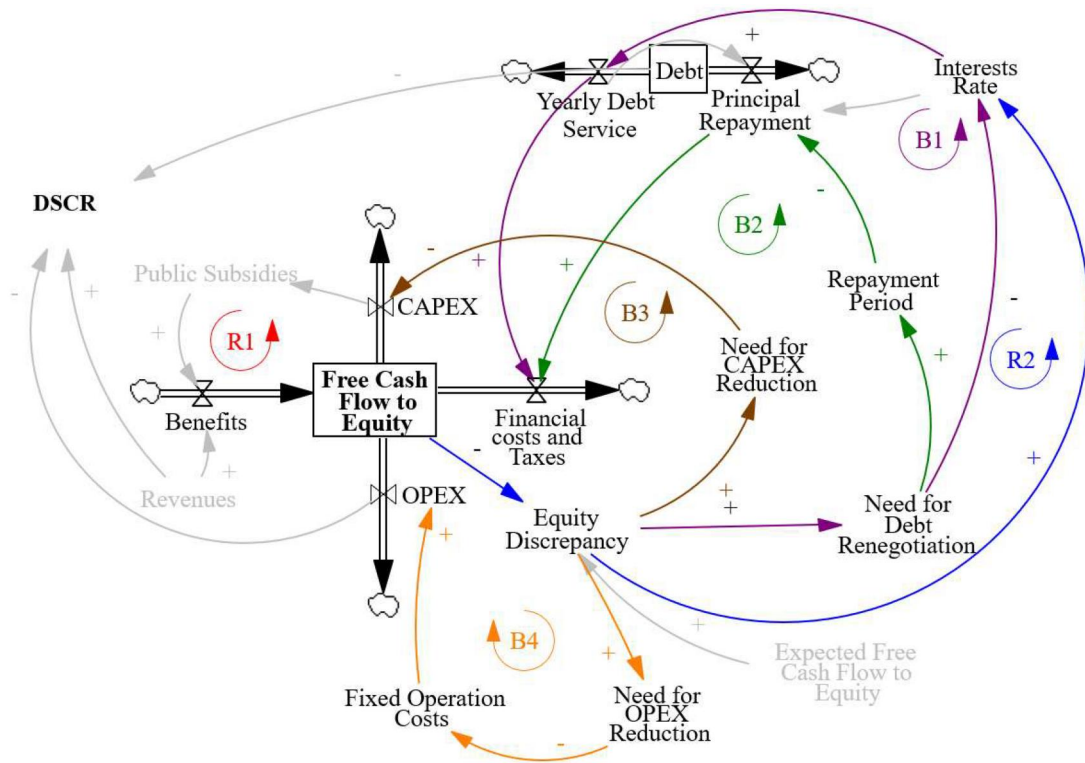


Figure 3. SFD.

This section is organized as follows: firstly, the baseline scenario is presented, providing a foundation for comparison. Then, the analysis focuses on improvements resulting from proposed interventions by the concessionaire. Following that, underperformance scenarios stemming from exogenous risks are examined. Finally, the impact of intervention implementation is assessed in each underperformance scenario. These findings contribute to understanding the potential strategies for addressing financial underperformance in toll road PPPs.

### Baseline scenario

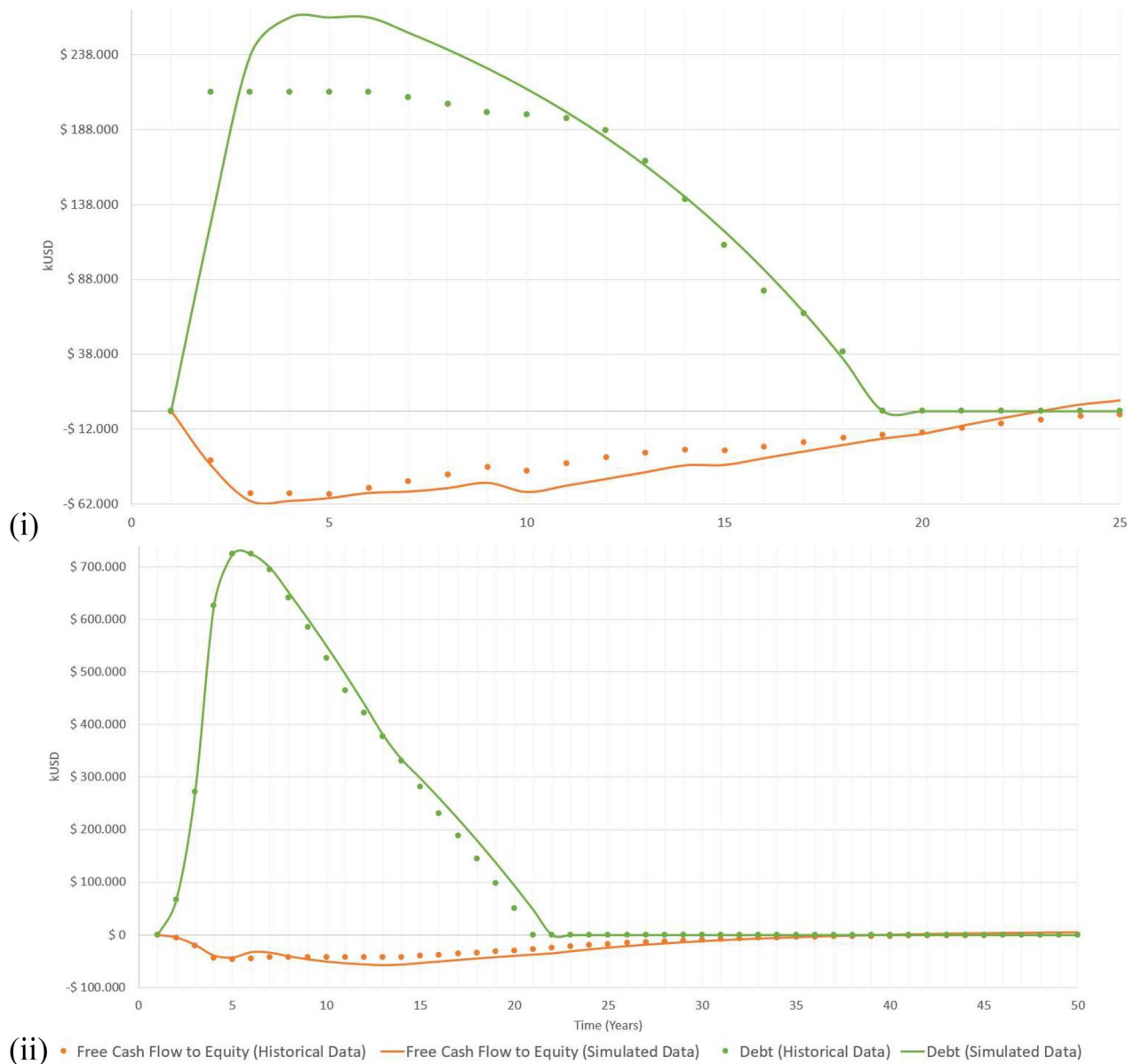
The results of the base run simulation are shown in Figure 4, which demonstrates that the simulated results (solid lines) follow the historical data (discrete data points). In this scenario, the *Debt* (green line) increases significantly in the short-term during the construction phase, while in the middle- and long-term decreases until is completely paid once the payment period is finished. Conversely, the *Free Cash Flow to Equity* shows a short- and middle-term declining trend where the *Revenues* are lower than the *CAPEX*, *OPEX*, and *Debt Repayment* but a positive trend drives recovery in the *Free Cash Flow to Equity* in the long-term to reach non-negative values once the concession period finishes.

According to Figure 4, during the first few years, there was a significant decrease in the *Free Cash Flow*. This initial behavior is entirely driven by the CAPEX balancing loop (B1 in Figure 2). The CAPEX is entirely financed by equity, debt (B2 & B4), and public subsidies (R1). Then, there is a momentary slight improvement in the cash flow in both projects, which is produced by the first revenues derived from tolls but the decreasing trend resumes due to the debt payments. Once the repayment periods finish, the cash flow increases more slowly as time passes because of the attenuation effect of the *IRR* on the balancing loops B2, B3, and B4 (Figure 2).

### Concessionaire's interventions through the PPP life-cycle

This study differentiates scenarios, which represent underperformance settings resulting from alterations in exogenous parameters beyond the concessionaire's control, from improvement interventions that the concessionaire can undertake to mitigate these underperformance issues.

Three concessionaire's interventions were established in the model (i.e. P1, P2, and P3) to analyze their impact in different phases of the project, considering the loops depicted in Figure 2 (i.e. R1, B1, B2, B3, and B4). This helped to establish suitable life-cycle



**Figure 4.** Behavior reproduction test for the baseline scenario. (i) Project 1; (ii) Project 2.

alternatives focused on addressing potential underperformance issues in each of the project phases. The interventions were tested for the whole concession period to assess their impact on the *Free Cash Flow to Equity* and *Debt Service Coverage Ratio (DSCR)* -i.e. a measure of the cash available to pay the debt obligations, computed as the ratio between the net operating income and total debt service-. Table 3 presents the three concessionaire's interventions under analysis and Figure 6 shows the impact of the concessionaire's interventions on the *Free Cash Flow to Equity* and *DSCR*.

P1 is an early proactive intervention resulting from CAPEX reductions in the initial phases of the project. This proactive intervention primarily focuses on advocating the adoption of a modular scope approach. This approach aims to introduce flexibility into PPP

projects, mitigating the adverse impacts of traffic shortfalls while simultaneously reducing the initial CAPEX investment. This intervention considers a CAPEX reduction of 20% from the baseline scenario, which is within the range that has been previously considered in the literature on financial models for PPPs (Xu *et al.* 2012). Consequently, this intervention is evidenced during the pre-construction phase resulting in improvements in the life-cycle financial performance through the balancing loop B1 (Figure 5).

P2 is a reactive intervention driven by renegotiating debt conditions with debt providers once the construction phase ends. In contrast to a proactive approach, a reactive intervention implies that the concessionaire waits until financial underperformance becomes noticeable before taking action by

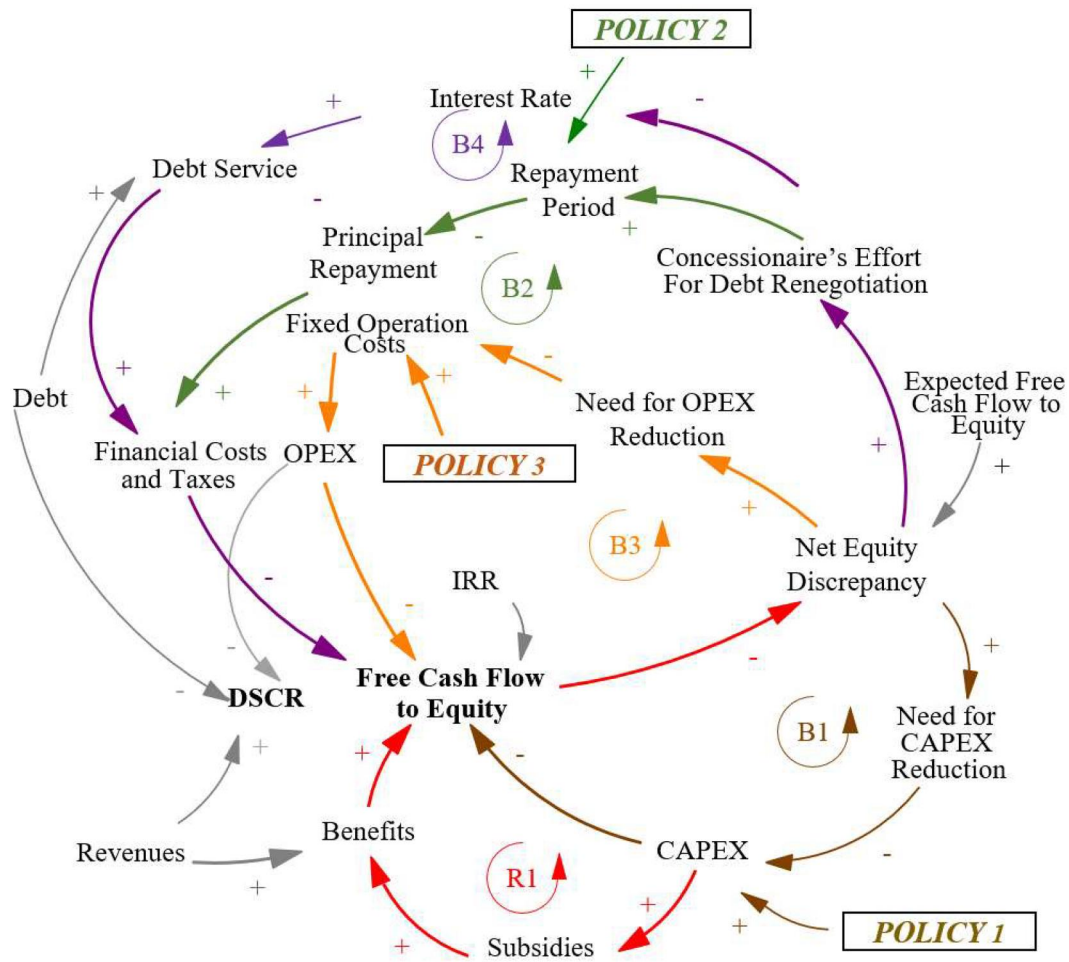


Figure 5. Impact of concessionaire’s interventions on the model’s feedback structure.

Table 3. Description of concessionaire’s interventions.

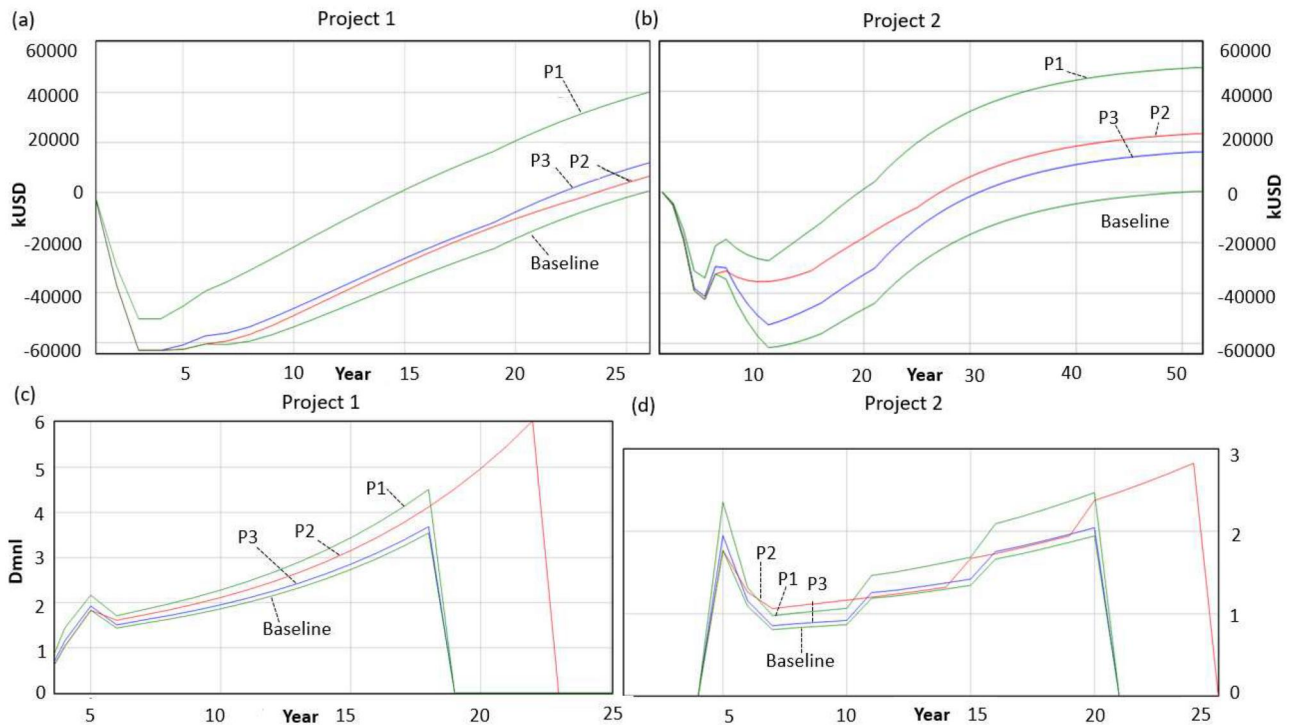
Concessionaire’s Interventions	Parameter	Adjustments		
		Baseline	Test Value	Units
P1: Reducing CAPEX	Variation Construction Cost/km	0	-20	%
P2: Renegotiating debt conditions	Variation Repayment Period	0	4	Years
P3: Reducing OPEX	Variation OPEX per Year	0	-20	%

implementing cost savings by renegotiating debt conditions. This reactive intervention only may be considered to address financial underperformance noticed before the operation phase, allowing the concessionaire to balance the *Net Equity Discrepancy* through B2 (Figure 5). This intervention is focused on modifying the repayment period by adding 4 years, which is suitable for debt providers considering that the rate of return of the debt will not be affected. Conversely, this model neglects to consider renegotiating the interest rate because of its inconvenience for debt providers and the further negative implications for the future of the debt market for PPPs.

P3 represents a late proactive intervention driven by OPEX reductions resulting from the concessionaire’s strategic decisions during the life-cycle. This is

achieved through strategic maintenance planning throughout the project’s life-cycle to optimize costs based on strategies such as adopting a condition-based maintenance approach instead of rigid maintenance schedules through the balancing loop B3 (Figure 5). This intervention considers an OPEX reduction of 20% from the baseline scenario, which is within the range that has been previously achieved as OPEX savings in multiple PPPs (Reis and Sarmento 2019).

According to Figure 6, the analysis of the interventions implemented over the Baseline scenario demonstrated that all of them produced significant improvements in the *DSCR* and *Free Cash Flow to Equity* for Projects 1 and 2. In respect to the *DSCR*, P2 allowed Project 1 to always exhibit values higher than 1.0 across the repayment period. Similarly, P2 helped



**Figure 6.** Effect of concessionaire's interventions on outcomes. (a) Cash Flow to Equity Project 1. (b) Cash Flow to Equity Project 2. (c) DSCR Project 1. (d) DSCR Project 2.

**Table 4.** Simulation results for the scenarios.

Type of Variable	Variable (Project)	Units	Baseline	S1	S2	S3
Parameter	Variation Interest Rate	%	0	1	0	0
Parameter	Variation Construction Cost/km	%	0	0	20	0
Parameter	Variation Initial Daily Traffic	%	0	0	0	-20
Output	FCFE (Project 1)	kUSD	577	-6692	-40718	-40984
Output	ADSCR (Project 1)	Dmnl	1.03	0.93	0.76	0.70
Output	FCFE (Project 2)	kUSD	255	-12990	-50313	-56038
Output	ADSCR (Project 2)	Dmnl	0.81	0.81	0.70	0.66

Note: S1 = Scenario 1 (Worse Debt Conditions); S2 = Scenario 2 (CAPEX escalation); S3 = Scenario 3 (Traffic underperformance); FCFE = Free Cash Flow to Equity (at the end of the concession period); ADSCR = Average Debt Service Coverage Ratio (Minimum).

Project 2 to increase its outcomes from 0.81 in year 7 to values above 1.0 after year 10. This is important because high *DSCR* values are required to guarantee both fulfillment of debt obligations and profitability (Damjanovic *et al.* 2016). On the other hand, in respect to interventions' impacts on the *Free Cash Flow to Equity*, there are differences in the long- and short-term for both projects. While *OPEX* reductions (i.e. represented by P3) produced the lowest positive effect in the long-term; P1 generated the highest positive impact across the early stages. These behaviors show that short-term financial improvements (B1) must be preferred over long-term enhancements (B3), considering that the attenuating effect of the *IRR* on potential positive alterations of financial outcomes increases as time passes. Overall, P2 constituted the most effective intervention for the improvement of the *DSCR* in Project 2, while P1 was more effective in Project 1.

### Scenarios based on underperformance conditions

Three scenarios were analyzed by considering realistic underperformance issues affecting the *Free Cash Flow to Equity*, namely: worse debt conditions, CAPEX escalation, and traffic underperformance. For doing so, base-run values of key exogenous parameters were modified to assess their impact on the system outcomes. These outcomes were compared against the baseline scenario of Projects 1 and 2, as shown in Table 4 and Figures 7 and 8.

Scenario 1 (S1) was established to understand the impact of underperformance on the debt arrangement according to the intended conditions. The parameter considered for this scenario was the *Interest Rate*. S1 considers an *Interest Rate* increase of 1% from the baseline scenario, which keeps the range of this parameter inside the interval of 4% and 12% reported in previous literature (Xu *et al.* 2012).

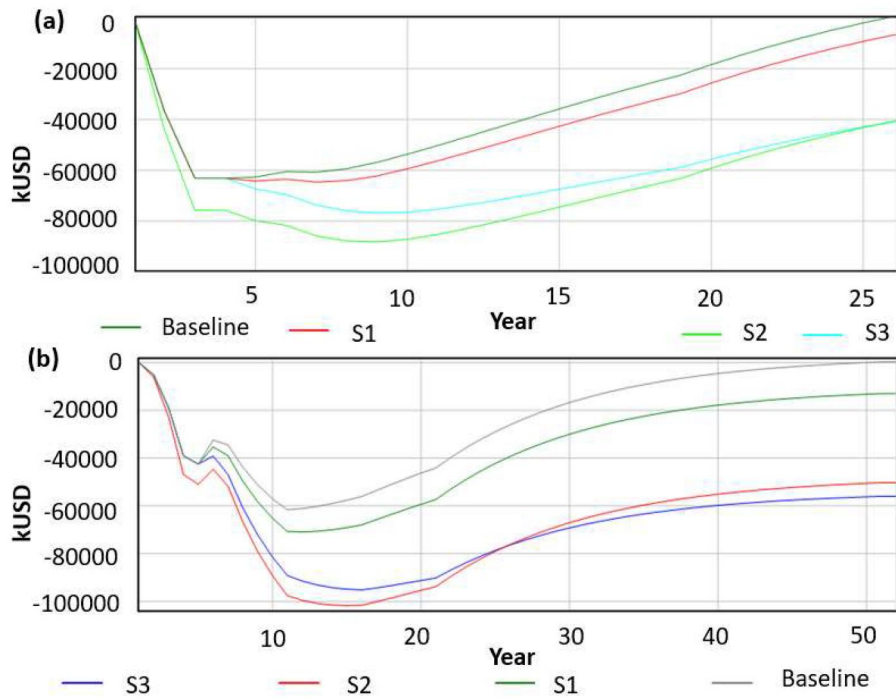


Figure 7. Results baseline vs. scenarios on the free cash flow to equity for project 1 (a) and Project 2 (b).

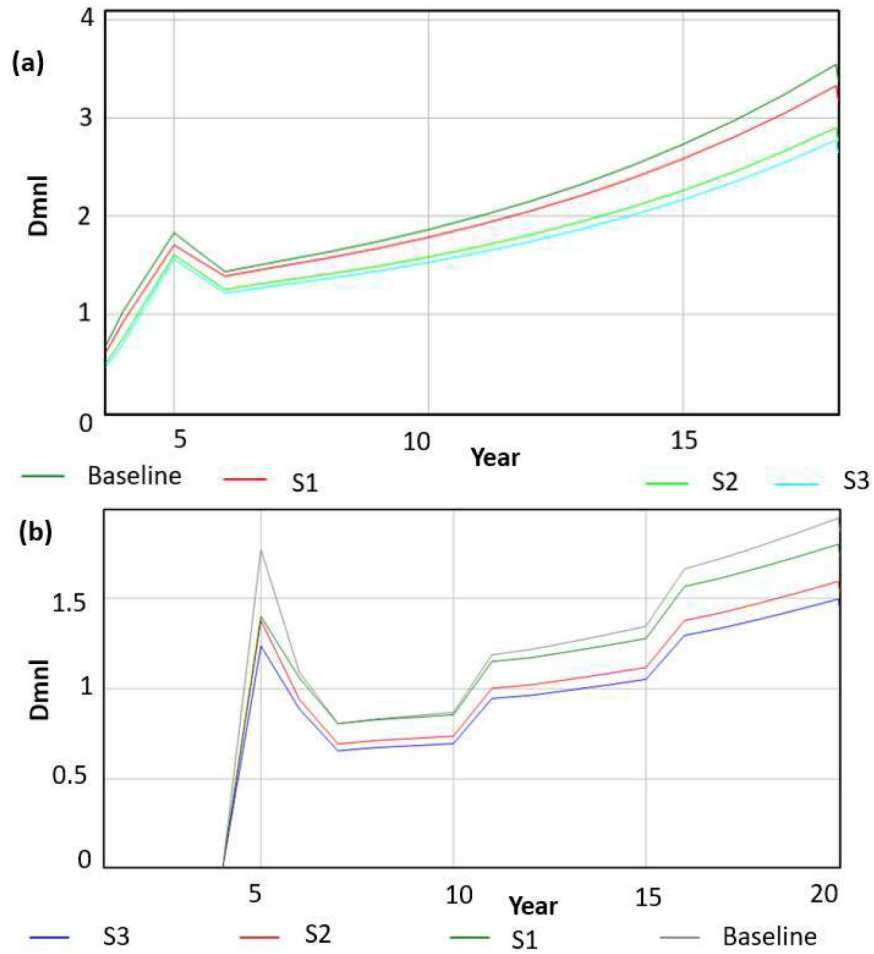


Figure 8. Results baseline vs. scenarios on the DSCR for project 1 (a) and project 2 (b).

Scenario 2 (S2) considers CAPEX escalations derived from exogenous risks, which is significantly different from CAPEX escalations taking place due to the concessionaire's decisions or mistakes. In this sense, this model considers that all the construction risk is allocated to the concessionaire, and, consequently, no contractual renegotiations would be allowed to compensate for this underperformance. This is a suitable assumption in countries such as the UK, China, Colombia, and Chile (Bing *et al.* 2005, Castelblanco *et al.* 2024a, 2024b, 2024c, Guevara *et al.* 2024, Rojas *et al.* 2023). Accordingly, for this scenario, the CAPEX was increased by 20% from the baseline scenario, which is consistent with CAPEX overruns up to 50% as suggested by Carpintero & Barcham (2012).

Scenario 3 (S3) was established to understand the impact of the variations of real traffic according to the forecasts. Such discrepancies were modeled by modifying the values of *Initial Daily Traffic* and *Traffic Growth*. This implies that the traffic risk is completely allocated to the private sector without any traffic guarantees, which is a common traffic risk allocation strategy in countries such as Brazil and Mexico (Carpintero & Petersen 2015). Based on that, this scenario assumed an *Initial Daily Traffic* decrease of 20% from the baseline scenario, which is a value inside the interval of variations between  $-80%$  to  $50%$  reported in extant case studies as stated by Alasad & Motawa (2016).

The analysis of the underperformance scenarios demonstrated that S3 constituted the most detrimental effect on the *Free Cash Flow to Equity* and *DSCR* for Projects 1 and 2 (Figures 6 and 7). Consequently, the traffic risk (S3) constitutes the most meaningful risk for the financial outcomes respecting the financial and construction risks. However, risks affecting the CAPEX (S2) represented the most significant underperformance for the *Free Cash Flow to Equity* in the middle term, which potentially may lead the concessionaire to

implement reactive interventions during the operation phase. Conversely, worsening in debt conditions (S1) resulted in the least detrimental effect, but still harmful, on the financial outcomes.

### Interventions and scenarios through the PPP life-cycle

The impact of the concessionaire's interventions on the underperformance derived from exogenous events (scenarios) is examined to understand the implications of early proactive, late proactive, and reactive improvements on the life-cycle financial performance, as shown in Table 5 and Figures 9 and 10.

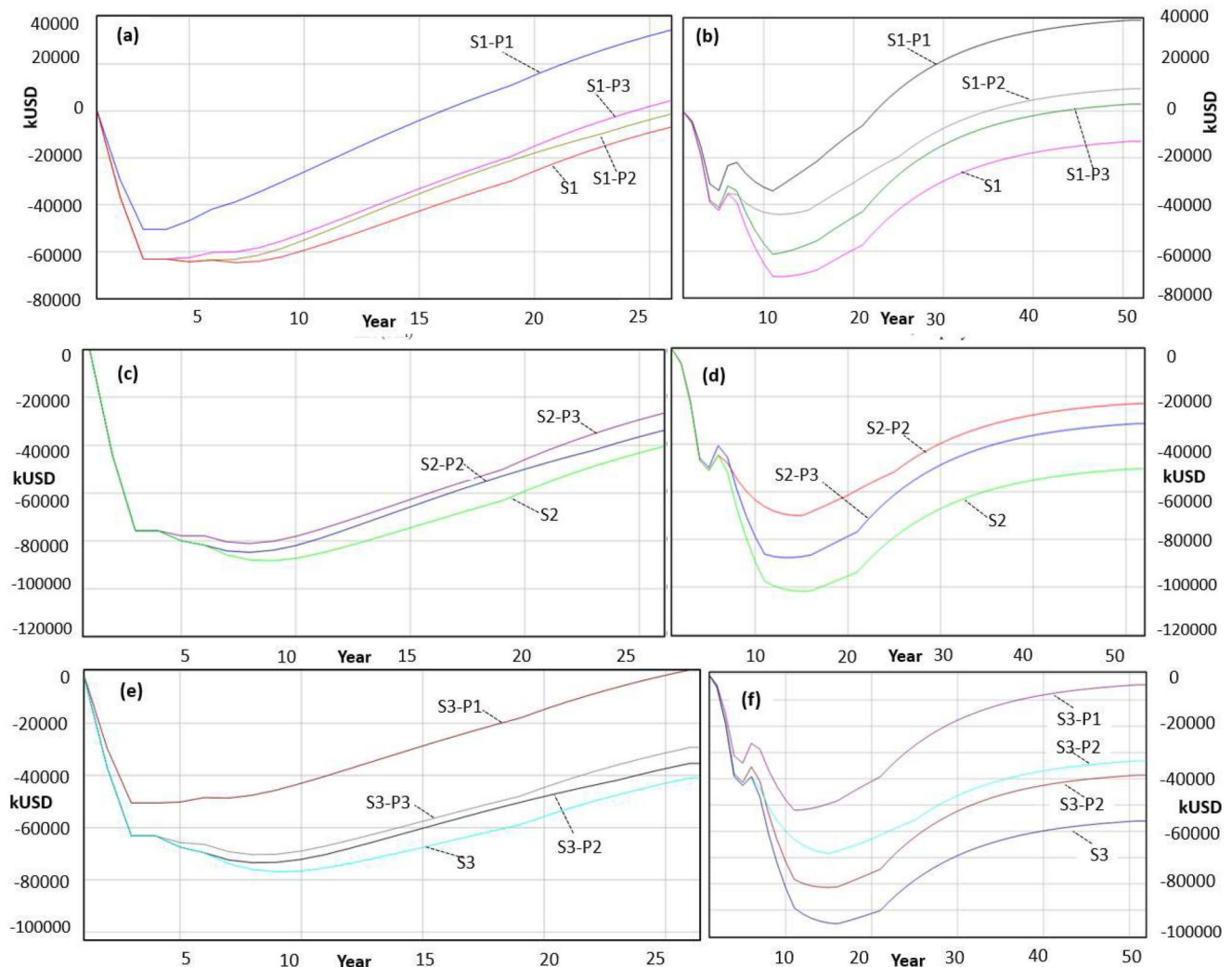
The analysis of the interventions implemented over the underperformance scenarios demonstrated that the concessionaire should prioritize early proactive intervention (CAPEX reductions-P1) driven by the balancing loop B1 to mitigate the affectations on its *Free Cash Flow to Equity*. Implementing an early proactive intervention resulted in the best performance for this outcome for all the scenarios in both projects analyzed (Figure 9 and Table 5). Consequently, short-term savings allow for a significant improvement of cash available during the construction phase (when it is more required) improving bankability and profitability.

Conversely, the effectiveness of early proactive intervention (CAPEX reductions-P1) for improving the *DSCR* depends on the level of debt of the project. In this regard, early proactive improvements (B1) only represented the highest positive impact on bankability in low debt-leveraged projects (Project 1 – where the debt constitutes 50% of the CAPEX), as shown in Figure 10 and Table 5. Alternatively, high debt-leverage projects (Project 2 – where the debt constitutes 90% of the CAPEX) achieved the most significant bankability improvements based on middle-term reactive interventions (B2-increasing the debt's repayment

**Table 5.** Description of concessionaire's interventions.

Scenarios (Project)	Output Variable	Base run	P1	P2	P3
S1 (Project 1)	FCFE	-6692	34684	-1140	4557
S2 (Project 1)	FCFE	-40718	NA	-33962	-26779
S3 (Project 1)	FCFE	-40984	461	-35357	-29258
S1 (Project 1)	ADSCR	0.93	1.29	0.93	1.03342
S2 (Project 1)	ADSCR	0.76	NA	0.76	0.878667
S3 (Project 1)	ADSCR	0.70	1.03	0.70	0.824206
S1 (Project 2)	FCFE	-12990	38992	9615	3009
S2 (Project 2)	FCFE	-50313	NA	-22931	-31387
S3 (Project 2)	FCFE	-56038	-4221.07	-33204	-38587
S1 (Project 2)	ADSCR	0.81	0.963384	1.04197	0.851055
S2 (Project 2)	ADSCR	0.70	NA	0.914382	0.740325
S3 (Project 2)	ADSCR	0.66	0.788444	0.864296	0.704767

Note. FCFE: Free Cash Flow to Equity; ADSCR: Average Debt Service Coverage Ratio (Min.); S1: Debt's interest rate escalation; S2: CAPEX escalation; S3: Traffic underperformance; P1: Reducing CAPEX; P2: Increasing debt's repayment period; P3: Reducing OPEX.



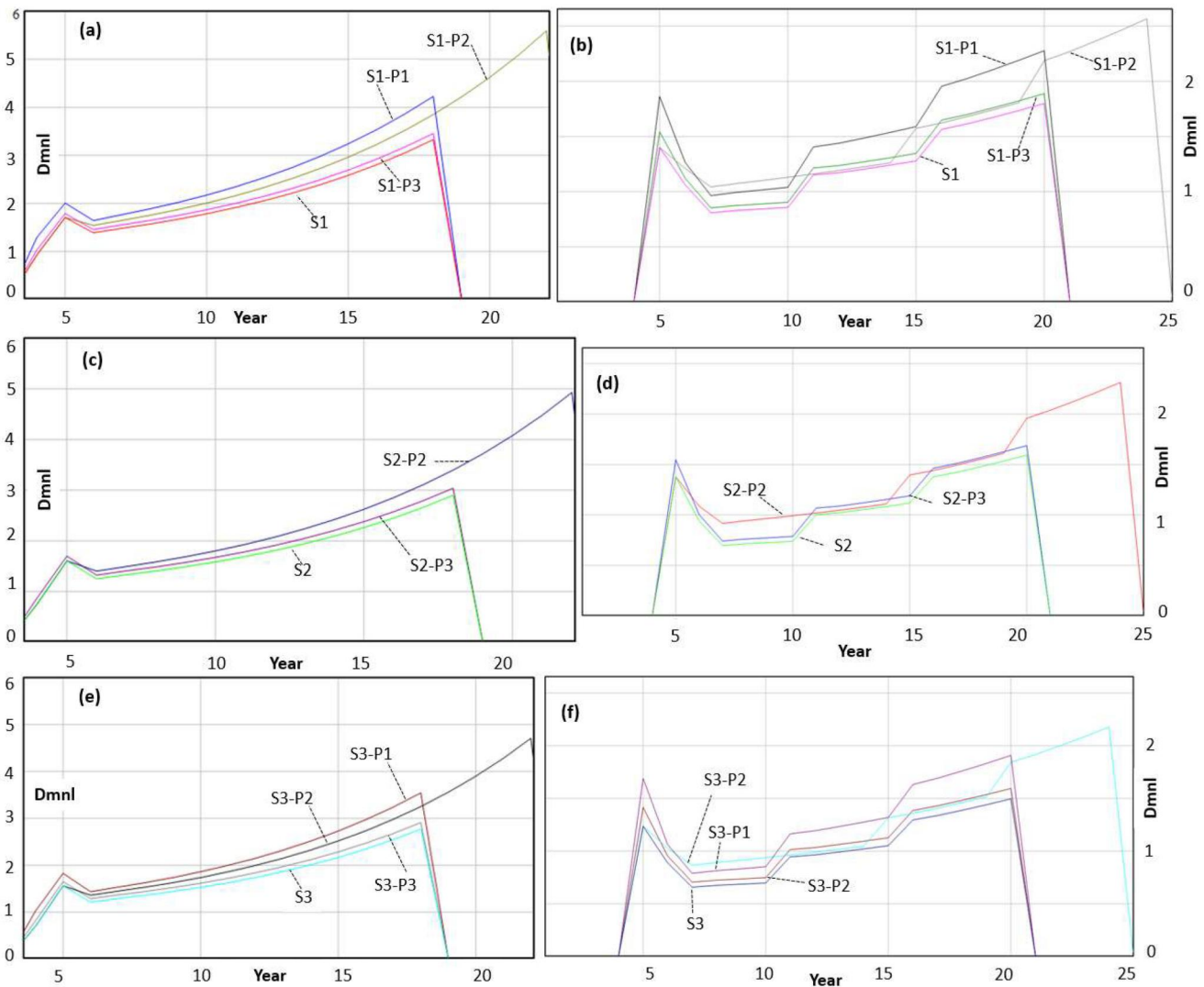
**Figure 9.** Effect of interventions on the free cash flow to equity for: (a) Scenario 1- Project 1. (b) Scenario 1- Project 2. (c) Scenario 2- Project 1. (d) Scenario 2- Project 2. (e) Scenario 3- Project 1. (f) Scenario 3- Project 2.

period). The dependence of B2 dominance on the level of debt should allow the concessionaire to prioritize reactive actions considering the specific features of the project.

The effectiveness of implementing a late proactive intervention (*OPEX* reductions-P3) also demonstrated a high dependence on the level of debt of the project for bankability and the concessionaire's profitability. Consequently, late proactive improvements (B3) represented the worst financial performance regarding the *Free Cash Flow to Equity* and *DSCR* for high debt-leveraged projects (Project 2) among all the interventions analyzed, as shown in Table 5. In contrast, for low debt-leveraged projects (Project 1) this intervention resulted in a better financial performance than reactive concessionaire's measures (increasing the debt's repayment period-P2), which demonstrates that the dominance of B3 also depends on the level of debt.

## Discussion

Although the existing literature contains studies focused on improving model forecast accuracy to mitigate uncertainty in long-term PPP projects and their financial performance impacts, the success of these efforts is limited due to the inherent bounded rationality linked with complex interdependencies and rapid external condition changes. Instead of exploring traditional forecasting models, this research focuses on an SD simulation tool aimed at enhancing decision-makers' comprehension of the system's intrinsic structure influencing the financial performance of user-pay PPPs. The proposed SD model integrates endogenous causal structures directly affecting project financial outcomes. It incorporates 'what-if' scenarios based on toll road projects with varying debt levels to quantitatively identify thresholds for specific policies to enhance flexibility within contractual frameworks.



**Figure 10.** Effect of interventions on the DSCR for: (a) Scenario 1 -- Project 1. (b) Scenario 1 -- Project 2. (c) Scenario 2- Project 1. (d) Scenario 2- Project 2. (e) Scenario 3- Project 1. (f) Scenario 3- Project 2.

Unlike existing literature, which often examines flexibility solely in terms of scope or financing parameters and is typically confined to specific project phases, results show the coexistence and mutual influence of flexibility in both scope and financing throughout the entire PPP life cycle—encompassing pre-construction, construction, operation, and maintenance phases. Accordingly, the significance of this research lies in addressing a gap in the current literature, where forecast models are restricted by inherent bounded rationality and flexibility has remained relatively unexplored and fragmented when considering user-pay road PPPs.

Elaborating on the concept of flexibility (Martins *et al.* 2014, Sismanidou and Tarradellas 2017), the proposed SD model extends its application to toll road PPPs by integrating flexibility into both scope and financing structure. In this way, findings shed light on

interventions that the public and private sectors may prioritize to mitigate potential financial underperformance, considering balancing loops tied to traffic, financing costs, CAPEX, and OPEX across the lifecycle phases. Consequently, the SD model allows for the examination of three financial improvement avenues in user-pay PPPs: reactive flexible debt, early CAPEX savings, and early scope flexibility through modularity

### **Flexibility in debt leverage**

Reactive financial improvements (P2 - increasing the debt's repayment period) constitute the most effective intervention for improving the DSCR for PPPs, especially those with a higher significance of debts in the financial structure. The comparison between the two projects demonstrated that when the significance of debt in a PPP is higher, the impact of flexibility in

debt conditions outweighs that of early proactive improvements (scope flexibility), from a bankability perspective.

The relevance of debt flexibility, particularly through extending the Repayment Period, carries significant implications for concessionaires. In instances of financial stress within a PPP project, concessionaires may prioritize renegotiating the debt repayment period as a more feasible option compared to renegotiating interest rates. This intervention's implications are particularly noteworthy for financing entities, emphasizing that addressing bankability issues in ongoing PPPs lies within the control of banking institutions themselves, without necessitating the renegotiation of interest rates, which is often impractical (Lenferink *et al.* 2014, Yescombe and Farquharson 2018). However, it is important to acknowledge potential barriers to implementing this intervention, such as constraints on the Repayment Period for certain types of debt, like bonds. These barriers could potentially be addressed with support from the public sector and multilateral financing entities (Yescombe and Farquharson 2018).

### **Early CAPEX savings**

The analysis of concessionaire interventions demonstrates that, from a life-cycle perspective, early proactive financial improvements (B1-reducing CAPEX) should take precedence over late proactive improvements (B3-reducing OPEX). This finding may appear counterintuitive given that the nominal value of Fixed Operation Costs is nearly three times that of CAPEX. However, this behavior arises from the role of the IRR as an attenuating factor in the long-term impact on OPEX (B3), compared to the short-term effect of CAPEX, which amplifies causal loops affecting immediate outcomes (B1). Life-cycle cost theory emphasizes the greater impact of costs during the operational phase compared to the construction phase (Galar *et al.* 2017, Hartwell *et al.* 2019). Conversely, this study demonstrates that due to the high private equity IRR in PPPs, short-term financial performance exhibits a higher incidence of private return compared to long-term financial behavior.

The significance of early proactive financial improvement through CAPEX is highlighted by model demonstrations revealing that CAPEX overruns, common in megaprojects, have a substantial financial impact comparable to that of traffic shortfalls and are even more critical than the effects of higher interest rates. Achieving early proactive CAPEX savings is

feasible for the SPV through alternative mechanisms such as promoting competitive procurement for subcontractors (Ahmed *et al.* 2022), optimizing the construction supply chain (Koc and Gurgun 2021), and maximizing economies of scale (Sherratt *et al.* 2020). However, these intended proactive behaviors for the construction phase must be carefully tailored due to potential conflicts of interest. Practices such as SPVs becoming construction subcontractors may lead to inappropriate subcontract arrangements and a lack of rigor in construction supervision (Yescombe and Farquharson 2018). Sponsors can mitigate these conflicts by involving other sponsors in construction subcontract negotiation and supervision. Additionally, financing entities should enforce preventive measures and thoroughly consider the cost performance of previous PPPs in which Concessionaire's partners have participated to assess the risk of payment default.

### **Early scope flexibility through modularity**

Scope flexibility through modularity involves the first intervention proposed in the SD model (B1-reducing CAPEX) focused on establishing a minimum upfront scope that can be expanded during the operation phase if actual demand exceeds specific thresholds. While this has been proposed in airport PPPs to optimize infrastructure capacity in response to demand fluctuations, recent literature indicates that its implementation in road PPPs is limited (Martins *et al.* 2014). Specifically, this practice has been mostly reduced to toll-managed lanes overseen by the public sector or to post-PPP expansions, rather than being integrated from the outset within contractual frameworks for interurban toll road PPPs managed by SPVs. For example, the absence of contractual provisions for lane additions in response to traffic changes was noted in the IJ Coen Tunnel in the Netherlands (Benitez-Avila and Hartmann 2023).

Procurement practices for interurban toll road PPPs typically favor inflexible long-term contracts that mandate upfront expansion. This preference often leads to issues such as excessive initial capacity expansion and costly renegotiations (Chung *et al.* 2010, Ullah *et al.* 2018, Acerete *et al.* 2019). Recent case studies have provided evidence of this kind of early renegotiation, particularly occurring between 5 and 10 years after contract commencement (Cruz and Sarmiento 2021). The detrimental effects of these early alterations in CAPEX on cashflow and bankability, as demonstrated by the interventions and scenarios analyzed by the SD model underscore the necessity for a flexible approach

in the scoping and contractual design of PPP projects to enhance long-term sustainability of such projects.

This adaptability is particularly crucial during times of crisis and for greenfield projects where traffic forecasts may be less reliable. To successfully implement this approach, a modular scope must be clearly established in the contractual arrangement, defining specific demand thresholds within certain time intervals during the operational phase. Additionally, it should be noted that the adoption of this approach in toll road projects presents distinct challenges compared to other types of transportation infrastructure, such as airports. While airports can expand capacity by constructing new terminals, toll roads are required to engage in strategic planning from the outset, addressing the full project scope to avoid adverse impacts over the project's life cycle. For instance, essential tasks like securing land and rights-of-way, conducting tunnel excavation, and constructing primary structural components should be undertaken early to accommodate the project's maximum potential scope, which may become necessary 15 years into the future based on traffic patterns. Decisions regarding lane expansion should be made based on reaching specific traffic thresholds. Adding extra lanes during the operational phase, while potentially affecting service levels, poses challenges akin to those faced during periods of intensive maintenance.

To effectively address these challenges, it is essential to deploy adaptive strategies that prevent traffic interruptions while prioritizing user safety. Leveraged on the interplay among traffic flow, revenues, and CAPEX demonstrated in the proposed model, lane expansions could be strategically planned for execution during extended off-peak periods. This approach is particularly beneficial for toll roads subject to annual cyclical traffic variations. By scheduling construction during off-peak months, toll road operators can guarantee lane expansion needs while minimizing service disruptions, thereby bolstering the project's success and sustainability.

## Conclusions

The proposed financial model enhances the understanding of the impact of interventions that the concessionaire may prioritize in different project phases and their effects on financial performance. The model reveals that two significant life-cycle drivers for addressing financial underperformance without contract renegotiations are early proactive improvements (CAPEX savings) and middle-term reactive actions

(increasing the debt repayment period). CAPEX reductions represent the only intervention capable of effectively addressing the most influential exogenous factor impacting the financial performance of PPPs, which is traffic shortfalls. PPP decision-makers can leverage this finding to promote flexible scopes through the implementation of modularity, allowing for a reduction in CAPEX during the early stages of the project while still ensuring acceptable service levels in the presence of traffic shortfalls or forecast inaccuracies. Conversely, middle-term reactive actions (increasing the debt repayment period) prove to be the most relevant alternative for improving bankability (minimum DSCR) in projects with higher debt leverage.

This paper strengthens the body of knowledge on PPPs in several ways. Firstly, the approach adopted in this study allows for an integrated life-cycle perspective. While various models have been proposed for assessing the financial performance of PPPs, they often focus on specific project phases and lack alternatives for addressing underperformances in each phase of the life-cycle. Secondly, the interventions analyzed from the concessionaire's perspective enable the development of a LCCA approach, aiming to establish suitable strategies for addressing underperformance based on specific practical interventions, such as modular scope approaches that have been previously proposed for airport PPPs. However, scope modularity has received relatively less attention in toll road PPPs, although there have been some promising initial attempts. Dividing the scope into functional units that can be built at different paces and times based on the evolution of traffic patterns is one possible implementation.

Thirdly, this study proposes increasing the repayment period to reduce bankruptcy risk in stressed PPPs without sacrificing profitability. Although there may be barriers to renegotiating the repayment period for certain types of debt, the support of the public sector and multilateral financing entities can help address these barriers when prioritizing the avoidance of early termination in stressed PPPs.

While this study provides significant findings to concessionaire decision-makers, it also has some limitations derived from the assumptions and scope established. The current financial model focuses on the concessionaire's perspective within toll road PPPs. Future extensions of this study could assess the public sector's perspective, considering social, institutional, and environmental benefits such as social welfare, taxes paid by the concessionaire, and reduction of CO2 emissions, among others. Additionally, further

research can focus on different categories of PPP infrastructure, such as social infrastructure. Moreover, future studies can incorporate diverse payment mechanisms, such as shadow tolls or availability payments, to compare the implications of non-user-pay PPPs. Lastly, future research should explore the financial ramifications of adopting a flexible scope, including the costs of additional works required in later stages, their effects on service levels during operation, and the potential for reducing initial capital outlays. This analysis will provide valuable insights into optimizing the financial and operational performance of toll road projects.

### Disclosure statement

No potential conflict of interest was reported by the authors.

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### Data availability statement

Data generated or analyzed during the study are available from the corresponding authors by request.

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