RESEARCH

Enhancing the decision-making process for public-private partnerships infrastructure projects: a socio-economic system dynamic approach

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Abstract

Public-private partnerships (PPP) have many critical socio-economic concession variables that need to be determined during the negotiation of the PPP contracts. However, their determination presents complexities to decision-makers due to these components' interdependencies. Assessing the dynamic and interdependent relationships between the socio-economic concession components can enhance the development of PPP concessions. System dynamics (SD) techniques have provided a holistic system understanding of several complex structures from a holistic perspective. This paper aims to build a novel socio-economic SD model to facilitate the decision-making process for PPP projects via determining and assessing the adequate concession period, concession price (user-payment), government subsidy, and the capital structure (in the form of equity). A case study for a PPP toll-road project (I-4 Ultimate) is utilized to validate the proposed model's results. Higher concession prices increased net present value (NPV) levels and PPP effectiveness. Simulation results showed that the variables are interdependent, and a change in the value of one variable will lead to a change in the values of the other variables. The results also showed that the concession price (user-payment) has a major influence on the concession variables. The model proposed in this study gives a holistic perspective of the complex interplay between PPP effectiveness and several socio-economic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects. While many scholarly discussions have been fronted on the use of system dynamics modeling in PPPs, the specific and unique combination of concession variables is the ultimate contribution of this study to the existing body of knowledge.

Keywords: Public-private partnership, PPP, Socioeconomic sustainability performance, Concession agreement, Infrastructure development, System dynamic

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Introduction

Background

The development of infrastructure is critical to the economic growth of any country. However, many governments cannot effectively meet the high demand for infrastructure without partnerships with the private sector. Governments often need to cooperate with private organizations to create a pool of resources that can be used to provide the necessary infrastructure. Developing infrastructure and providing public services is often resource-intensive. As a result, governments cannot solely acquire resources to meet these needs [1]. Public-private partnerships (PPP) are long-term agreements in developing infrastructure constructed between public and private parties [2]. The private sector's role in PPPs includes designing, developing, managing, financing, and operating government projects. Countries can build their infrastructures through PPPs, thus fostering economic growth and development [3, 4].

Conversely, PPP has been found to generate enormous economic benefits, such as access to finance, technology, skills and expertise, personnel, risk transfer, business development, and investment opportunities. Governments play a vital part in the infrastructural development of their countries. However, specific dynamics such as high population and increased urbanization make it difficult for governments to adequately meet citizens' infrastructure needs. As a result, PPPs become necessary to complement government efforts in enhancing efficiency and effectiveness in delivering services to citizens. PPPs utilize capital and expertise in the private sector to supplement the government's efforts in providing services and developing infrastructure. Although PPPs effectively ensure infrastructure development and provide essential services, the model faces significant challenges in its execution.

PPPs play a critical role in the economies of both developed and developing countries. However, the approach faces significant challenges that often derail collaboration and cooperation. PPP projects face many developmental challenges, including dynamic complexities, nonlinearities, and time delays [5–9]. Over the recent years, the critical concession variables (price and period) have presented significant complexities for decisions and policymakers [10–12]. Some of the critical concession variables are time and cost [13], equity and debt [14], and cash inflows and outflows [15]. By assessing these concession variables, the development of PPP would be possible. Hence, using the System Dynamics (SD) modeling technique may effectively overcome these challenges.

The SD model examines the relationships between the cause and effects in the forms of stock-flow diagrams and feedback loops [16]. Techniques for system dynamics (SD) have provided a more profound understanding of the holistic perspective of PPPs. Shire et al. [17] suggested that system dynamics (SD) is an approach that helps to recognize the non-linear performance of systems that are too complex to understand. Besides, SD acts as an effective tool for generating insights into dynamic complexity and policy resistance [18]. Moreover, the SD model can provide system feedback from a holistic perspective. As recently posited, many economists worldwide are starting to embrace SD as an essential tool for including their non-conventional thoughts into formal models [19]. Therefore, the current study hypothesizes that assessing the dynamic relationship between the concession factors and components using a novel SD model can enhance the decision-making process in developing PPP agreements. The first significance of this study is that

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it combines more than one socio-economic variable in assessing the effectiveness of PPP using the SD model. Though this model has been under serious scrutiny, it is now being embraced by economists worldwide for its ability to include new approaches in understanding how PPP can improve socio-economic variables. Second, it can be the basis for further investigations into country-specific PPP effectiveness. The assumptions therein can be tested and modified accordingly depending on the interactions among the socio-economic variables. Third, this study is a timely reminder that policymakers have vital roles to play in ensuring that policies encouraging how PPP improves socio-economic variables are set up and may give insights on how to boost local production.

Literature review

In this review, studies have taken different approaches to apply the systems dynamics technique in modeling public-private partnerships scenarios. The biggest difference among them is that they consider other concession variables. Many studies have been conducted to examine one aspect or another in the PPP development process using the SD methodology. For example, the concession period, which sometimes the government decides without any justification, is one of the agreed-upon parameters when engaging in PPPs. Thus, this induces frequent renegotiations due to the uncertainties in the market. Various models of SD have been used to determine the realistic period for concession. Despite this, existing models assume that perfect information is always available. This seems unreasonable for real-life projects since information is always imperfect for them. Ullah et al. [20] created an SD modification tool for the concession period based on understanding the critical success factors that affect the selection of the concession period. Determining the PPP projects' period for a concession is usually a complex decision due to many factors. Fifty-nine concession factors were chosen, with the results showing that the concession period ought to be dynamic (depending on the NPV, the concession can be either increased or reduced after some time) rather than fixed. They concluded that a dynamic concession period could create a win-win scenario for the involved public and private parties. Despite this, the Ullah et al. [20] study does not lay down the critical success factors that determine this period. Therefore, this provides a significant limitation for the study. Like the reviewed study, the paper in focus seeks to leverage the systems dynamics technique in modeling the relationships between key concession variables. Jin et al. [21, 22] proposed a game theory approach to negotiating the concession period for PPP highway projects, which determines both sectors' behavior and, thus, reaches a consensus about the period of the PPPs.

On the other hand, the SD approach investigated financial concession factors in the PPP literature. Pagoni and Patroklos [23] proposed an SD model to study PPP development's sustainable economic and social strategies. A novel SD model was proposed to determine how sustainable PPPs were. The causal-loop diagrams revealed that the management of PPP programs constituted complex dynamic systems [23]. Conversely, experimentation using numbers was employed to evaluate the influence of a change in public policy on the PPP program's sustainability. They discovered that the system dynamics tool employed provided a strategic tool for decision support when developing PPPs. However, the sustainability performance of the PPP programs was only tested against one variable: public policy. At the same time, other variables may also affect the

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sustainability performance of the PPP projects. Zhang et al. [24] created an SD tool to examine a PPP highway development financing strategy. They concluded that the model could be a valuable means to support the decision-making process in choosing an adequate financing strategy. Xu et al. [11, 12] utilized an SD methodology to examine the concession price for highway development. Their findings outlined that using the proposed model can obtain a win-win setup for the involved parties. Despite this, they discovered that various risk factors arose during price determination. Just like the studies reviewed above, the paper in focus adopts the systems dynamic technique in its modeling approach.

Du et al. [14] performed a study on the PPP's capital structure's critical factors. Capital structure is usually crucial to ensuring that PPPs have sufficient funds. Nonetheless, they indicated that having an inappropriate capital structure would lead to many PPP projects' failure. Seven critical factors (benefit, cost, risk, government support, project condition, external situation, and the private sector's ability) impacted the PPP projects' capital structure as identified by Du et al. [14]. The cited paper used the qualitative comparative analysis (QCA) to obtain information that would then go into the system dynamics model based on 15 PPP projects. However, it did not incorporate scientific techniques, and thus, its results and findings could have been biased. Lv et al. [25] developed a tool to determine the appropriate subsidies for railway projects. Through a system dynamics approach, Lv et al. [25] identified a level of acceptable government subsidies, which ensured that the Urban Rail Transit project was viable. This study incorporated the Monte Carlo Simulation tool and system dynamic technique to determine the acceptable range of subsidy.

Similarly, a sensitivity analysis was conducted, which revealed that the equilibrium position for a subsidy ratio optimal for PPP programs increased as the private sector's loss factor (assets or resources paid for but cannot be used) inclined. Besides, it was found to increase when the public sector had a strong position. The results and findings by Lv et al. [25] indicated that the loss factor for both the private and public sectors significantly influenced the equilibrium for the subsidy ratio. Notably, the implications of this study by Lv et al. [25] can serve as the basis for future modeling scenarios. Firstly, information uncertainty was one of the limitations that impacted decision-making. Secondly, the lower and upper-lower limits of the subsidy and the uncertainty of quasi operational PPP projects (not fully owned by the government or private partner) were other limitations that influenced this study's findings. Therefore, in the future, the government would need to consider the balance of stakeholders' interests in quasi-operational PPP projects and the construction and operating period subsidy.

Balancing the interests of the PPPs involved parties were also investigated in the literature. Yuan et al. [26] proposed an SD tool to balance the investors' satisfaction in developing a PPP bridge project via regulating the government subsidy and concession price. They concluded that the project could obtain more significant benefits by taking the price adjustment in the concession agreement into account. However, the model did not include the debt and equity ratios of the project development, which can significantly impact the results of the simulations. Feng et al. [27] studied how to balance the PPP's stakeholders' interests. For PPP projects paid by the users, the private sector would collect fees from the users to cover the project's cost and, thus, reap sales from it. The public

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sector would use the public funds for projects that cannot be financed through user-pay. Feng et al. [27] indicated that risks and revenues would be allocated to balance interests through a concession agreement. The main limitation here is that different opinions may arise concerning the contract. For example, the public sector's main aim is to use public resources more efficiently, while the private sector is concerned with earning money. To solve this, they developed a multi-objective optimization model. The results and findings revealed that the technique could produce possible combinations for the items in the agreement that balance the involved parties' interests. Berrone et al. [28] argued that sustainability is the long-term ability to sustain the PPP operations to benefit all stakeholders. A summary table is given in Table 1.

However, most of the SD studies conducted in the PPP literature have neglected some concession factors, such as the capital structure of the PPP agreements and the public subsidies. Hence, investigating the system from a holistic perspective, including significant financial and social components and parameters that significantly impact it,

Table 1 Concession variables and models used by previous studies

S/N	Concession variables	Model used	Reference
1	Demand forecasting	System dynamic	Alasad et al. [29]
	Concession price and period	Road concession model	Arata et al. [30]
2	Concession price and period	System dynamics causal loop (SDCL)-empirical testing model	Asiedu and Ameyaw [5]
3	Concession period	The "win-win" model and Monte Carlo simulation	Carbonara et al. [31]
	59 variables, including investment size, concession period, and project income	System dynamic	Ullah et al. [20]
	Public policy	System dynamic	Pagoni and Patroklos [23]
	Benefit, cost, government support, external situation, and private sector's ability	System dynamic	Du et al. [14]
4	Concession period, price, capital structure, government subsidy, and sustainability performance	The multi-objective optimization model	Alghamdi et al. [32]
	Subsidies, loss factor, and public sector position	Monte Carlo simulation	Lv et al. [25]
5	Concession period	Concession period-mathematical model (partly assumptions-based)	Feng et al. [33]
6	Concession period and toll-rate structuring	Dual-variable approach	Gross and Garvin [34]
7	Internal return rate, payback tariff, and concession period	Stepwise approach (no model followed)	Hadi and Erzaij [35]
8	Concession period	Game theory-evaluating model	Jin et al. [21, 22]
9	Concession period and revenue sharing rate	Monte Carlo and risk premium approach	Kokkaew and Tongthong [36]
10	Concession period	Empirical model	Liu et al. [37]
11	Various critical performance factors include legal, technological, procurement, and economical.	Quantitative approach	Opawole et al. [38]
12	Concession price	System dynamic	Xu et al. [11, 12]
13	Concession price	Principal-agent theory	Yuan et al. [39]
	Subsidy and Concession Price	System dynamic	Yuan et al. [26]
14	Concession period	System dynamic	Zhang et al. [40]

is pertinent to understanding how PPP can improve and sustain socio-economic variables. The SD model for developing PPPs needs to take most of the critical concession components such as the concession period, concession price (user-payment), government subsidy, and the capital structure into account to better examine the system from a socio-economic sustainability perspective. Previous studies have indicated that these components are long-term indicators of how successful the PPP will be [11, 12, 41, 42]; hence, they are considered in the present study.

Methods

The model development process follows a systematic approach, including qualitative and quantitative steps (Fig. 1) following previous studies ([, 11, 12, 43, 44];). The qualitative process starts with problem identification, which outlines the need for the model and the research goal. Then the identification of the model parameters and the system conceptualization (which can be seen in the causal loop diagram (CLD)) to outline the system's feedback. After that, the quantitative process starts with the model formulation (based on the stock and flow diagram) and the model validation. In this section, the study identifies the problem, determines the parameters of interest, conceptualizes the modeling system, formulates the model, and validates it.

Problem identification

PPP has many critical socio-economic concession variables that need to be determined during the negotiation period of developing the PPP contracts. However, these critical concession variables' determination presents complexities to decision-makers due to these components' interdependencies. Many studies feature the selected concession variables as exogenous variables and can be assumed not to be directly influenced by other concession variables. Assessing the dynamic and interdependent relationships between the socio-economic concession components can enhance the development of PPP concessions.

System dynamics (SD) techniques have provided a deep system understanding from a holistic perspective in several complex structures [17, 45, 46]. The paper in focus aims to build a novel socio-economic SD model to facilitate the decision-making process for PPP projects via determining and assessing the adequate concession period, concession price (user-payment), government subsidy, and the capital structure (in the form of
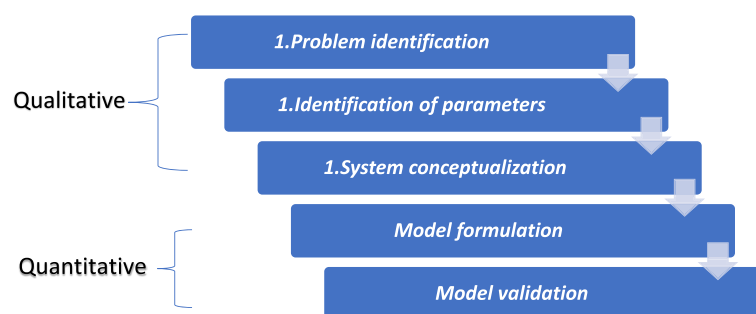

Fig. 1 The model development process

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equity). A case study for a PPP toll-road project (I-4 Ultimate) will be utilized to validate the proposed model's results. The proposed model should act as a valuable tool to facilitate and enhance the decision-making process for PPP projects based on a systematic and holistic point of view.

Identification of parameters

In this section, model variables are defined as:

- Endogenous variables that are interactive within the system (influencing all the other variables)
- Exogenous variables which are factors that are not enclosed by the system boundary but influence the system (constants not influenced by variables held within the system)

The model's exogenous variables were traffic volume growth rate, interest rate, capitalized interest rate, construction period, construction cost, inflation rate, tax rate, and discounting rate. On the other hand, endogenous variables were concession period, concession price, government subsidy, equity, equity ratio, debt ratio, traffic volume, operations and maintenance cost, debt repayment, and payment on debt interest. Tables 2 and 3 show a summary of these parameters, including their units of measurement.

System conceptualization

The approaches posited by several previous studies were considered in the current research, from model concept development to validation [11, 12, 44, 49, 50]. To illustrate the interdependent relationships between the PPP concession variables and assess the system feedback, we build a CLD (Fig. 2). The CLD describes the cause-and-effect relationships by tracing the directions of the arrows. Each arrow is denoted by a positive polarity (direct relationship) or negative polarity (inverse relationship) to illustrate the relationship between the variables better. The total project investment is a combination of debt and equity, and the more equity the project acquires, the less debt will be needed (Fig. 2, B1). These equities can be divided into private and public equities. To

Table 2 Model variables identification

Endogenous variables (units)	Exogenous variables (units)
Concession period (years)	Traffic volume growth Rate (%)
Concession price ($ dollars)	Interest rate (%)
Government subsidy ($ dollars)	Capitalized interest rate (%)
Equity (%)	Construction period (years)
Equity ratio (%)	Construction cost ($ dollars)
Debt ratio (%)	Inflation rate (%)
Traffic volume (cars/day)	Tax rate (%)
O&M cost ($ dollars)	Discounted rate (%)
Debt repayment ($ dollars)	
Payment on debt interest ($ dollars)	

Table 3 Model parameters for the I-4 Ultimate

Parameter	Unit	Value	Reference
Capital structure	Billon dollars ($)	2.3	[47, 48]
Construction period	Years	6	[47]
Equity level	Percentage (%)	6	[47]
Loan capitalized interest rate	Percentage (%)	5	Assumed
Loan interest rate	Percentage (%)	3	Assumed
Traffic volume	Vehicle/day	70,000	Assumed
Discounted rate	Percentage (%)	5	[47]
Tax rate	Percentage (%)	3	Assumed
Concession period	Years	40	[47, 48]
Concession price	Dollars ($)	9	Assumed
Total subsidy	Billion dollars ($)	0.4	Assumed

fulfill the equity ratio, there is a tradeoff between private and public equity values (Fig. 2, B2). Also, debt and cash outflow have a directly proportional relationship. For example, obtaining more debt will increase the amount of the total interest rate to be paid. Hence, to curb against massive cash outflows, there is a need to consider more equity than debt in the capital structure (Fig. 2, B4, B5, and B6). Besides, to maintain an appropriate value of NPV, the total cash inflows need to be higher than the total cash outflows (Fig. 2, B7). The traffic volume and the concession price (user-payment) should be high to increase the total cash inflows. Care should be taken in setting the concession price optimally because a higher-than-normal concession price will result in fewer vehicle owners willing to use the toll road (Fig. 2, B8).
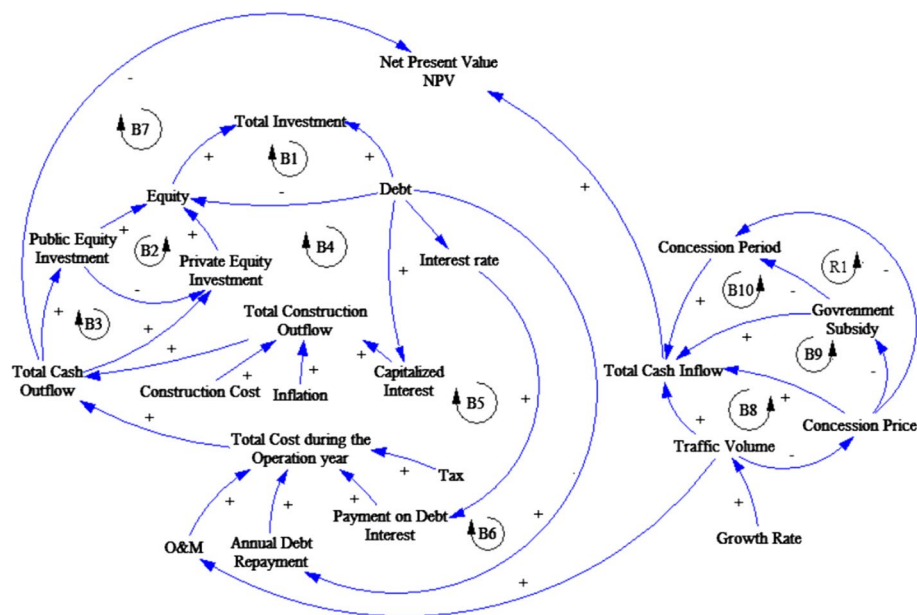
Fig. 2 Causal loop diagram

Furthermore, a higher government subsidy yields higher cash inflows, and the greater the subsidy is, the less the concession price (user-payment) value will be needed to meet the required cash inflows (Fig. 2, B9). On the other hand, the concession period significantly impacts the total cash inflows. The more the concession period is, the greater the cash inflows; however, the concession period has inverse relationships with the concession price (user-payment) and the government subsidy (Fig. 2, B10 and R1).

Model formulation

In this section, several variables are included to power the model. The formulation of the model followed our previous research [32]. Capital structure refers to the relative proportion of debt and equity that form the total capital outlay for the project. Debt is money obtained as a loan from financial institutions, which is to be paid back with interest. Equity is the amount of money the private and or public partner pays towards funding the project.

Total investment

The project's total investment is defined as the summation of debt and equities (Fig. 3) and can be expressed using the following formula:

$$Total\ Investment = private\ equity + public\ equity + debt \tag{1}$$

$$Debt = \left(1 - Equity\right) \times Capital\ structure \tag{2}$$

$$Equity = private\ equity + public\ equity \tag{3}$$

Therefore, the equity ratio is given by:
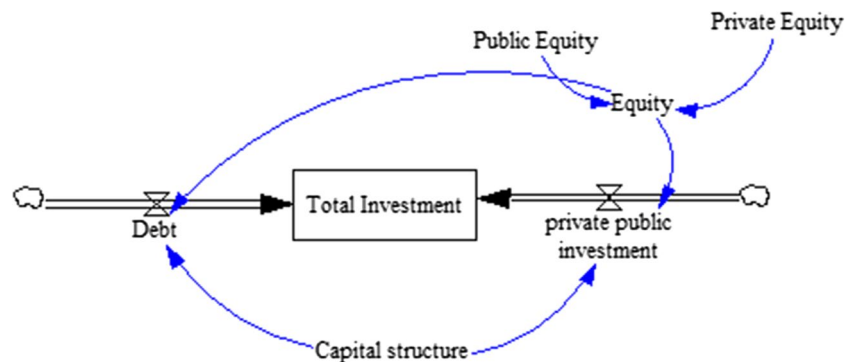
$$e = \frac{Equity}{Equity + Debt} \tag{4}$$

Fig. 3 Stock and flow diagram for total investment

Cash outflow

The total cash outflow (TCO) extends throughout the concession period and is defined as the summation of the total construction cost (TCC) and the total operational cost (TOC). The construction cost is computed during construction, considering the inflation rate and the expenditure due to the capitalized interest on the loan. However, the operational cost is zero during the construction period as the project is not functioning. Likewise, the construction cost is zero during the operational period. Hence, the TCO can be modeled using the stock and flow diagram shown in Fig. 4.

To calculate the TCO, the following equations are considered:

$$TCO_i = TCC_i + TOC_i \tag{5}$$

$$TCC_i = BC_i + EC_i + IC_i \tag{6}$$

$$BC_i = \begin{Bmatrix} \frac{C}{CP} & if \ i \le CP \\ 0 & if \ i > CP \end{Bmatrix} \tag{7}$$

$$EC_i = BC_i \times \left(\prod_{f=0}^{i-1} \left(1 + r_f \right) \right) \tag{8}$$

$$IC_{i-1} = (1 - E) \times BC_{i-1} \prod_{f=0}^{i-1} \left(1 + r_f \right) \left(1 + r_c \right)^{CP-I+1} \tag{9}$$

where;

$BC_i = base\ construction\ cost$; $EC_i = escalation\ cost\ or$ increase in cost due to inflation; $IC_i = monetry\ value$ of capital interest on debt; $CP = construction\ period$; $r_f = inflation\ rate$; $r_c = capitalized\ interat\ rate$; $E = Equity$; $C = capital\ structure$

The total cost during the operational year can be computed using the following formula:

$$TOC_i = OMC_i + ADI_i + INT_i + TAX_i \tag{10}$$

$$OMC_i = \begin{Bmatrix} OMC_o \times \prod_{n=0}^{i} \left(1 + r_f \right) & if \ i > CP, i \le CP + OP \\ 0 & if \ i \le CP \end{Bmatrix} \tag{11}$$

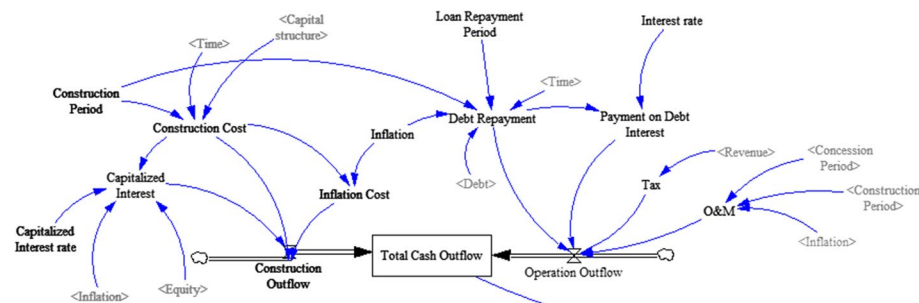**Fig. 4** Stock and flow diagram for the total cash outflows

$$\begin{cases} ADI = PR \times \frac{r \times (1+r)^{RN}}{(1+r)^{RN}-1} & if\ i > CP \& i \le CP+RN \\ \qquad\qquad 0 & if\ i < CP \& i > CP+RN \end{cases} \tag{12}$$

$$PR = \frac{(1-E) \times C}{RN} \tag{13}$$

$$Tax_i = (REV_i - INT_i) \times k \tag{14}$$

where:

ADI_i = annual debt installment at year i; INT_i = interest payment on debt at year i

TAX_i = payment of tax at year i; k = tax rate

RN = loan repayment period; OMC_i = operation and maintenance cost at year i

Cash inflow

During the concession period, the total cash inflow (TCI) combines the total revenue generated and the monetary value of the subsidy injected during the operational year [51, 52]. Revenue is generated on the PPP project during the operational year. The total revenue is a function of the traffic volume and the concession price. The stock and flow diagram for the TCI is shown in Fig. 5. While user toll is a common measure and determinant of cash inflow, its inclusion in this model was forfeited in favor of daily traffic volume. In the context of a toll road project, the two metrics are assumed to be synonymous.

The annual revenue (Rev_i) is generated by the daily traffic volume (T_i) and the annual concession price (p_i) and is defined as follows:

$$Rev_i = 365 \times T_i \times p_i \tag{15}$$

where:

Rev_i = annual revenue

T_i = daily traffic volume

p_i = unit concession price

Hence, the annual total cash inflow (TCI_i) during the operational year is the summation of the annual revenue (Rev_i) and the annual subsidy (which can be expressed as the total subsidy (G) divided by the operational year (OP)). A subsidy is a government financial aid to an industry or organization to promote the establishment of specific
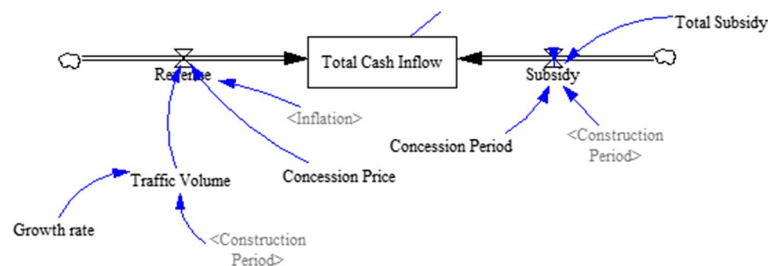

Fig. 5 Stock and flow diagram for the total cash inflows

infrastructure or development of an area or ensure an organization's prices remain low. Authorities appreciate that without these subsidies, the private sector would be reluctant to engage in certain projects or produce certain commodities. Indeed, not all PPP projects have subsidies. In case the government does not provide them, the second parameter in Eq. 16 will evaluate to zero. The ultimate annual TCI will be equal to the total annual cash inflow for the year.

$$TCI_i = Rev_i + \frac{G}{OP} \tag{16}$$

where:

TCI_i = annual total cash inflow

Rev_i = annual revenue

G = government subsidy

OP = operational year

The concession price can be modeled as a function of the inflation rate given the proposed concession price at the beginning of the simulation. Also, the traffic volume can be modeled as a function of the growth rate given the estimated initial traffic volume. In cases where the traffic volume decreases, T_i will also decrease because of the direct relationship between the initial and current/annual traffic volume, as evidenced in Eq. 18. The opposite is true for when the traffic volume increases, making the model relevant regardless of demand uncertainty.

$$p_i = p_o \times \prod_{n=0}^{i} \left(1 + r_f\right) \tag{17}$$

$$T_i = T_o \times \prod_{n=0}^{i} \left(1 + g\right) \tag{18}$$

where:

p_o = initial conession price; r_f − inflation rate; T_o = initial Traffic volume; g = growth rate

Net Present Value (NPV)

The NPV is modeled using the discounted rate return (d) and is defined as the difference between the discounted total cash inflow and the total cash outflow (Fig. 6), and it is expressed as follows:

$$NPV_i = (TCI - TCO) \times (1 + d)^{-i} \tag{19}$$

where:

NPV = net present value

TCI = total cash inflow
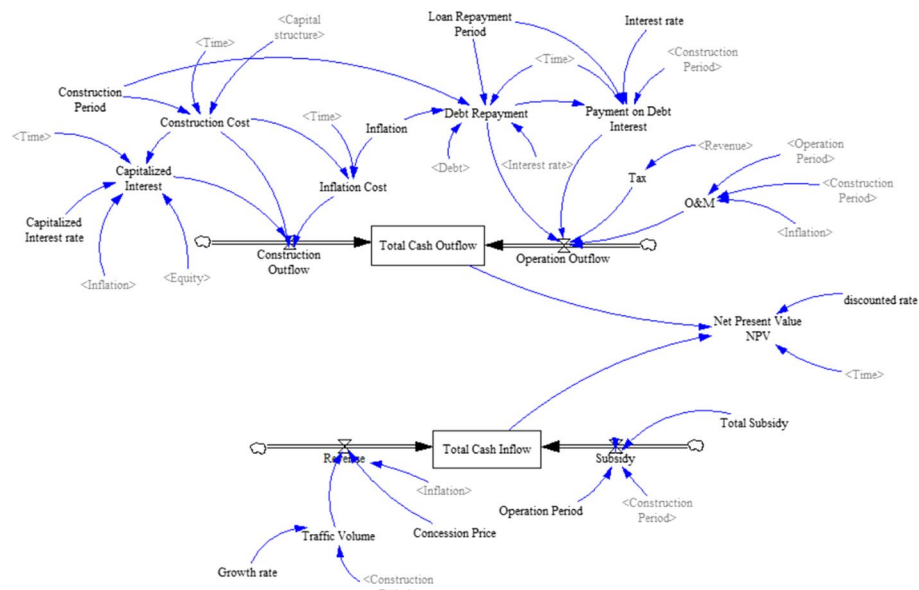
TCO = total cash outflow

d = discounting rate

Fig. 6 Stock and flow diagram for the net present value

Fig. 7 Stock and flow diagram for the DSCR

Debt Service Coverage Ratio (DSCR)

The DSCR is used to compute the ability of the investment to repay all its debt during the loan repayment period. It is defined as the ratio of the profit before tax and the annual debt installment. The DSCR (Fig. 7) can be calculated using the following formula:

$$DSCR_i = \left\{ \begin{array}{ll} \frac{1}{RN} \sum_{t=0}^{RN} \frac{REV_i - TAX_t}{ADI_t} & if \ i \leq RN \\ 0 & if \ i < RN \end{array} \right\} \tag{20}$$

where:

DSCR = debt service coverage ratio

RN = loan repayment

REV = revenue

ADI = annual debt installment

Socioeconomic sustainability indicator

The socioeconomic sustainability indicator describes the level of sustainability of the PPP project based on the critical endogenic variables and the concession terms. Sustainability is the degree to which a PPP project satisfies the interests of the private and public partners. Because both parties' interests are met, the project is more likely to attain short- and long-term goals. The objective is to measure how sustainable the concession terms are designed to maximize the return on investment and public interest simultaneously. Recent studies have indicated that the public and investors will be more confident to invest in every PPP setting and give a vote of confidence if their interests are protected. Investment returns are a key driver for effective PPP activities [53, 54]. In this regard, the public interest is measured based on the affordability of the PPP project (indicated by the concession price (user-payment)) and the ability to minimize public investment (indicated by the public equity and the amount of the subsidy). Also, weighting (*w*) is introduced to prioritize any concession parameter based on its importance. The weighting of the concession parameters is subjective and can be selected based on the significance of the parameter. Thus, while determining the weights, the rule of thumb is that parameters with a more likely impact on sustainability, such as NPV, should be scored with bigger weights. The socioeconomic sustainability indicator (Fig. 8) can be calculated using the following formula:

$$
\begin{aligned}
s = w_1 \times \frac{NPV}{NPV_{max}} + w_2\left(1 - \frac{G - G_{min}}{G_{max} - G_{min}}\right) + w_3\left(1 - \frac{OP - OP_{min}}{OP_{max} - OP_{min}}\right) \\
+ w_3\left(1 - \frac{p - p_{min}}{p_{max} - P_{min}}\right) + \left(1 - \frac{Equity - Equity_{min}}{Equity_{max} - Equity_{min}}\right)
\end{aligned}
\tag{21}
$$

Assumptions

- The project begins to yield revenue the year after the construction period ends.
- The loan is assumed to be obtained from a source with a capitalized interest during construction and a current interest rate during the operational year.
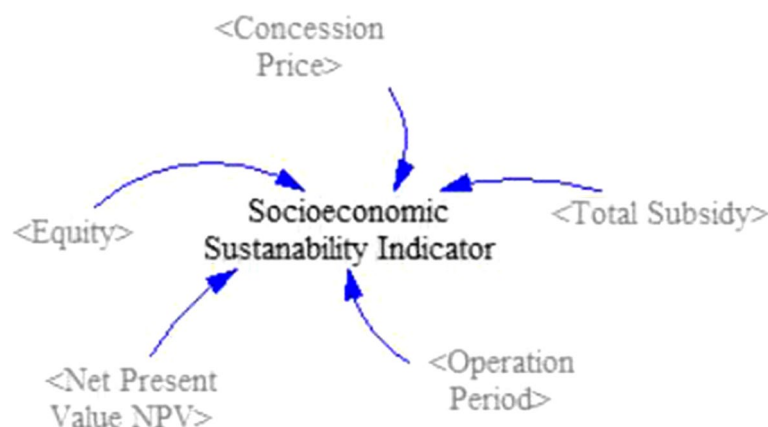

Fig. 8 Stock and flow diagram for the Socioeconomic Sustainability Indicator

- The concession price is the average toll charge for all users, and it increases throughout the contract period due to inflation. For this reason, the costs will be reviewed once every year to account for inflation.
- There is no depreciation on the project all through the contract period.
- An annual inflation rate of 1% is assumed throughout the contract period.
- The subsidy is injected only during the operational year to harness the operational and maintenance cost.

The case study

The US I-4 Ultimate is a PPP project owned by the Florida Department of Transportation (FDOT). The project spans 21 miles and links Kirkman Road to State Road 434 [48]. The project's entire cost was anticipated to be $2.3 billion, including the replacement of 74 bridges, the expansion of 13 bridges, and the construction of 53 new ones, in addition to the rehabilitation of 15 key interchanges and the addition of four additional express lanes to I-4's central section. The tolls for the project are collected electronically, and the cost is based on the demand. Traffic demand around the project is estimated to be 200,000 vehicles/day [48]. Hence, the demand of 70,000 vehicles/day is assumed in this study. Also, for simplicity, a $9 concession fee for a passenger to travel the 21 miles is considered for this study, which is a reasonable range based on previous projects along I-4. Passengers in Miami, for example, pay between $0.5 and $10.50 to go 7 miles on the 95 fast lanes [48]. The project started its first operational year in February 2022. Table 3 shows the model parameters for the I-4 Ultimate.

Results and discussion

The case study is presented and demonstrated using the Vensim dynamic simulation software to validate the SD model. The SD model was validated using the parameter in Table 3. The model validation was carried out by collecting and observing the operational cost, revenue, and NPV at the beginning and end of the operation period. Table 4 shows the model validation results for the case study. It justified the expected dynamic behavior of the SD model formulated in the previous section, indicating that the operational cost and generated revenue increase throughout the simulation. While the operational cost increases due to inflation and loan repayment, the generated revenue increases due to the price inflation and the growth in traffic volume.

The dynamic behavior of the NPV, the DSCR, and the socioeconomic sustainability indicator can be observed in Figs. 9, 10, and 11, respectively. The results show that the NPV increases dynamically from negative to positive from the 8th year. The initial

Table 4 Model validation results for the US I-4 Ultimate

Concession period	Description	Operational cost	Revenue	NPV
7	The beginning of the operation period	$138.1 M	$255.3 M	− $2.34 B
40	The endpoint of the concession period	$88.69 M	$583.8 M	$273 M

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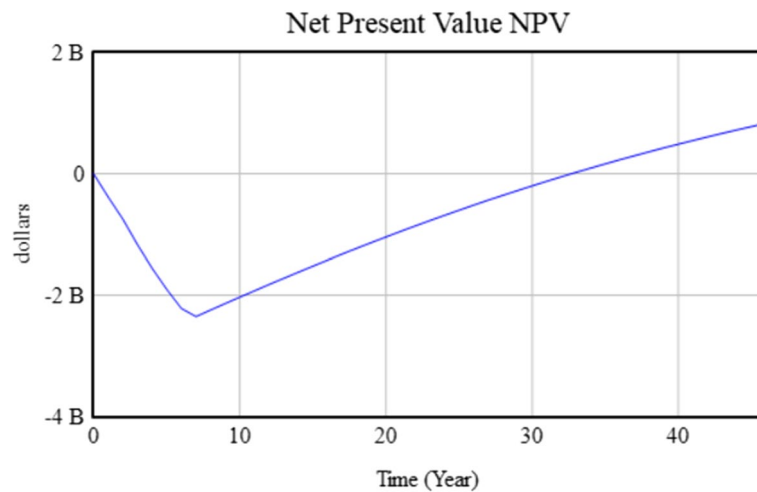
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Fig. 9 The dynamic NPV results for the I-4 Ultimate
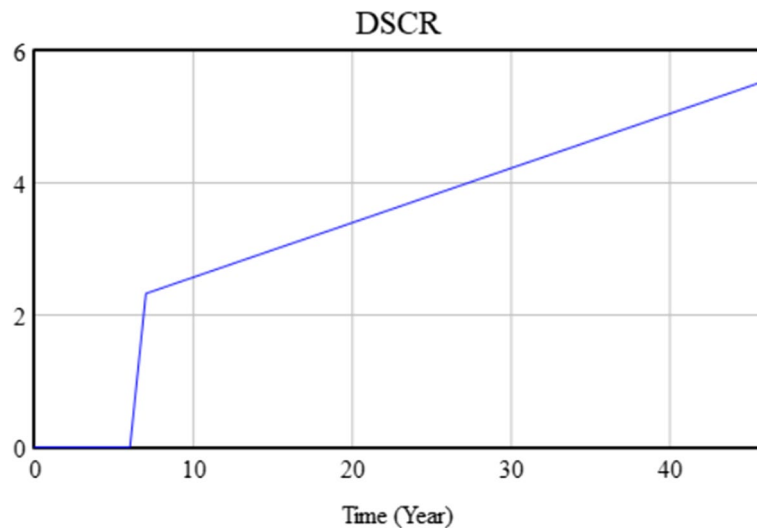

Fig. 10 The dynamic DSCR results for the I-4 Ultimate

stage of the simulation describes the dynamic behavior of the construction period, which indicates a large negative NPV due to the construction cost. As the concession year increases (moves forward), the NPV increases due to the revenue generated until it reaches a value of $273 million at the end of the concession period (Fig. 9). The DSCR increases dynamically as the project generates revenue and repays its debt from the 8th year (Fig. 10). The socioeconomic sustainability indicator increases with the operational period (from 8.5 years onwards) as the project generates revenue (Fig. 11).

Sensitivity analysis

Effects of changing a concession parameter on the other concession parameters

The sensitivity analysis tests the effects of changing a concession component's value on the other concession components' values. The tests were conducted using a range of − 30% to + 30% at a step size of 10% of the initial concession variable value. A
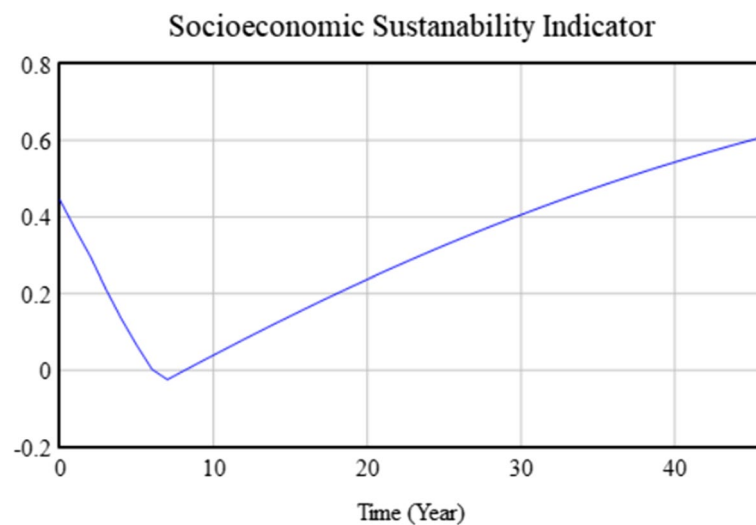
Fig. 11 The dynamic socioeconomic sustainability indicator results for the I-4 Ultimate

Table 5 Effects of changing the concession price on the other concession parameters

Concession price ($)	6.3	7.2	8.1	9	9.9	10.8	11.7
Concession period (years)	52	52	44	38	32	28	28
Equity (%)	7.8	7.8	6.6	5.4	5.1	4.5	4.2
Subsidy (M$)	520	520	480	480	340	300	280
NPV (M$)	-520	-2.6	103	109	103	107	410

minimum NPV value of $100 million was set to determine how much change in the other concession components' values is needed to meet the minimum NPV value.

Effects of changing the concession price (user-payment) on the other concession parameters
The effect of changing the concession price (user-payment) on the other concession components was tested using the sensitivity range of − 30 to 30% at a step size of 10%, given an initial concession price of 9$. Other concession variables were adjusted to balance the effect of the changes to meet the minimum value of the NPV ($100 M). This sensitivity test aims to observe how much change in the other concession variables is required to obtain the minimum NPV for the range of sensitivity tests. Table 5 shows the sensitivity test results on the concession price (user-payment) with other concession variables for the case study. The other concession terms (concession period, subsidy, and equity) were adjusted to meet the minimum NPV of $100 M.

Effects of changing the concession period on the other concession parameters
The effect of changing the concession period on the other concession components was tested using the sensitivity range of − 30% to 30% at a step size of 10%, given an initial concession period of 40 years. Other concession variables were adjusted to balance the effect of the changes and meet the minimum value of the NPV ($100 M). This sensitivity

Table 6 Effects of changing the concession period on the other concession parameters

Concession period (years)	28	32	36	40	44	48	52
Concession price ($)	11.5	10.5	9.5	8.7	8.2	7.7	7.3
Equity (%)	7.8	6	5.7	5.4	4.8	4.5	4.2
Subsidy (M$)	420	400	360	320	300	280	280
NPV (M$)	102	109	102	101	101	105	101

Table 7 Effects of changing the concession equity on the other concession parameters

Equity (%)	4.2	4.8	5.4	6	6.6	7.2	7.8
Concession period (years)	42	42	41	41	41	40	40
Concession price ($)	8.5	8.48	8.48	8.48	8.45	8.45	8.45
Subsidy (M$)	440	420	420	380	380	370	320
NPV (M$)	113	110	105	107	109	100	105

test aims to observe how much change in the other concession variables is required to obtain the minimum NPV for the range of sensitivity tests. Table 6 shows the sensitivity test results on the concession period with other concession variables for the case study. The other concession terms (concession price (user-payment), subsidy, and equity) were adjusted to meet the minimum NPV of $100 M.

Effects of changing the concession equity on the other concession parameters
The effect of changing the concession equity on the other concession components was tested using the sensitivity range of − 30% to 30% at a step size of 10%, given initial concession equity of 6%. Other concession variables were adjusted to balance the effect of the changes and meet the minimum value of the NPV ($100M). This sensitivity test aims to observe how much change in the other concession variables is required to obtain the minimum NPV for the range of sensitivity tests. Table 7 shows the sensitivity test results on the concession equity with other concession variables for the case study. The other concession terms (concession price (user-payment), concession period, and subsidy) were adjusted to meet the minimum NPV of $100 M.

Simulation results showed that the variables are indeed interdependent, and a change in the value of one variable will lead to a change in the values of the other variables. For example, looking at Table 5, the higher the value of the concession price (user-payment) is, the lower the values of the concession period, subsidy, and equity will be needed to meet the minimum NPV ($100 M). Similarly, Tables 5 and 6 showed the same behavior when altering the concession period and equity. The simulation results support other findings in the field [11, 12, 32]. The simulation results also showed that the concession price (user-payment) has a major influence on the concession variables.

Effects of change in the concession price (user-payment) on the NPV and the socioeconomic sustainability indicator
The effect of changing the concession price was carried out in the SD model to test the dynamic behavior of the NPV and the socioeconomic sustainability indicator. The
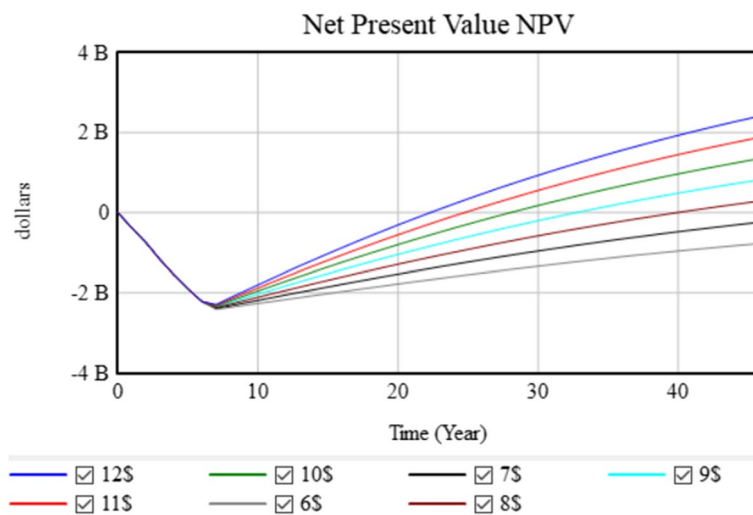
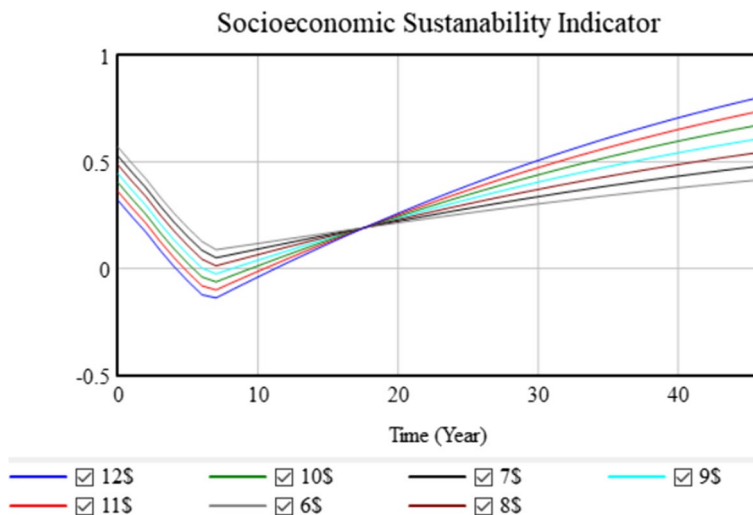**Fig. 12** The NPV dynamic behavior for the concession price change

Fig. 13 The Socioeconomic Sustainability Indicator dynamic behavior for the concession price change

concession price (user-payment) was changed while the other concession components remained the same. The resulting dynamic behaviors are shown in Figs. 12 and 13. The results show that the more the concession price, the more NPV the project will obtain. It can be clear that with a higher concession price, the project will require a shorter concession period to meet the minimum attractive NPV. The socioeconomic sustainability indicator has almost identical behavior to the NPV; the more concession price, the higher the indicator level.

Conclusions

This paper aimed to build a novel socio-economic SD model to facilitate the decision-making process for PPP projects via determining and assessing the adequate concession period, concession price (user-payment), government subsidy, and the capital structure

(in the form of equity). A case study for a PPP toll-road project (I-4 Ultimate) was utilized to validate the proposed model's results. The NPV increased due to the revenue generated until it reached a value of $273 million at the end of the concession period. The DSCR increases dynamically as the project generates revenue and repays its debt from the $8.1 concession price mark. Higher concession prices also resulted in increased NPV levels and PPP effectiveness. Simulation results showed that the variables are interdependent, and a change in the value of one variable will lead to a change in the values of the other variables. For example, looking at Table 5, the higher the value of the concession price (user-payment) is, the lower the values of the concession period, subsidy, and equity will be needed to meet the minimum NPV ($100 M). Similarly, Tables 5 and 6 showed the same behavior when altering the concession period and equity.

The simulation results also showed that the concession price (user-payment) has a major influence on the concession variables. The socioeconomic sustainability indicator has almost identical behavior to the NPV; the more concession price, the higher the indicator level. The model proposed in this study gives a holistic perspective of the complex interplay between PPP effectiveness and several socio-economic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects. The ability of the model to capture several concession variables in a non-linear fashion makes the systems dynamic (SD) model suitable for application in the given PPP or build-operate-transfer (BOT) project situation. Models assuming the linearity of the relationship between concession variables and the target variable do not fit this context. The most significant limitation of this paper is that it does not include all the concession variables and critical indicators relevant to the infrastructure development sector. Future research can expand the SD model by including other critical indicators such as the impact of uncertainties, risk-allocation, interdependencies, among other concession variables, and value for money. From the sustainability perspective, the model has investigated some of the PPPs' economic and social dimensions; however, other economic and social dimensions and the environmental dimension were not fully considered. Hence, including the effects of these dimensions can play an essential role in future research.

Abbreviations

PPP	Public-private partnership
SD	System dynamics
CLD	Causal loop diagram
DSCR	Debt service coverage ratio
NPV	Net present value
IRR	Internal rate of return
ROE	Return on equity
DCF	Discounted cash flow
TCO	Total cash outflow
CC	Construction cost
OMC	Operational and maintenance cost
TCI	Total cash inflow
FDOT	Florida Department of Transportation
PFAL	Project Finance Advisory Ltd
BOT	Build-operate-transfer

Declarations

Competing interests
The authors declare that they have no competing interests.

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