Enhancing the Decision-Making Process for Public-Private Partnerships' Concession Agreements: Socio-Economic Sustainability Approaches

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ENHANCING THE DECISION-MAKING PROCESS FOR PUBLIC-PRIVATE PARTNERSHIPS’ CONCESSION AGREEMENTS: SOCIO-ECONOMIC SUSTAINABILITY APPROACHES

by

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A dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Civil, Environmental, and Construction Engineering in the College of Engineering and Computer Science at the University of Central Florida Orlando, Florida

Summer Term 2022

Major Professor: Omer Tatari
ABSTRACT

Designing a concession for Public-Private Partnerships (PPP) agreements is a complicated process due to the number of variables that need to be considered. The PPP concession has many parameters and components, and a change in one component will considerably impact other components. Hence, the determination of the fair values of the concession components needs to be based on mutual benefits between the concession participants. The concession participants have different parts in the development of the concession; hence, they have different perspectives and goals. Therefore, the concession design needs to be constructed to balance the interests of the involved parties to ensure a smooth and sustainable development of the project.

The first phase of this dissertation aims to build a Socio-Economic System Dynamic (SD) model to facilitate and enhance the decision-making process for PPP projects. It should help determine and assess the adequate concession period, concession price (user-payment), government subsidy, and capital structure. Also, a Socio-Economic Sustainability indicator will be provided to evaluate the Socio-Economic Sustainability Performance for the given case study. The model proposed in this phase provides a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects.

The second phase of this dissertation aims to build a Socio-Economic Multi-Objective Optimization (MOO) model to help determine the optimal concession values. It should provide possible values for several concession factors (concession period and price, government subsidy, and capital structure). Also, a Socio-Economic Sustainability indicator will be provided to assess the Socio-Economic Sustainability Performance for the given case studies. The proposed model aims to
simultaneously optimize the values for the different concession variables when they are dependent on each other, considering the trade-offs between the components. Having these contribution options can facilitate and enhance the decision-making process for both the public and private parties.
To my beloved mother (Lola),

who has sacrificed so much for my success.

To my beloved wife (Leena),

who has always offered me with her unconditional love, encouragement and supports.

To my beloved children (Talia & Abdul Aziz),

who have brought happiness and joy to my life.

To my brother and sister (Bader & Bedoor),

who have supported me toward my success.

To my family and friends,

who have always been there for me.
ACKNOWLEDGMENTS

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<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>BOT</td>
<td>Build Operate Transfer</td>
</tr>
<tr>
<td>CLD</td>
<td>Causal Loop Diagram</td>
</tr>
<tr>
<td>CC</td>
<td>Construction Cost</td>
</tr>
<tr>
<td>DSCR</td>
<td>Debt Service Coverage Ratio</td>
</tr>
<tr>
<td>DCF</td>
<td>Discounted Cash Flow</td>
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<tr>
<td>FDOT</td>
<td>Florida Department of Transportation</td>
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<tr>
<td>GA</td>
<td>Genetic Algorithm</td>
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<tr>
<td>IRR</td>
<td>Internal Rate of Return</td>
</tr>
<tr>
<td>MOO</td>
<td>Multi-Objective Optimization</td>
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<tr>
<td>NPV</td>
<td>Net Present Value</td>
</tr>
<tr>
<td>OMC</td>
<td>Operational and Maintenance Cost</td>
</tr>
<tr>
<td>PFI</td>
<td>Private Finance Initiative</td>
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<td>PFAL</td>
<td>Project Finance Advisory Ltd</td>
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<tr>
<td>P3</td>
<td>Public Private Partnership</td>
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<tr>
<td>PPP</td>
<td>Public Private Partnership</td>
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<tr>
<td>ROE</td>
<td>Return on Equity</td>
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<tr>
<td>SD</td>
<td>System Dynamic</td>
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<td>TS</td>
<td>Thompson Sampling</td>
</tr>
<tr>
<td>TCI</td>
<td>Total Cash Inflow</td>
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<tr>
<td>TCO</td>
<td>Total Cash Outflow</td>
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CHAPTER 1: INTRODUCTION

1.1 Overview and Motivation

Public-Private Partnership (PPP) may be seen as a constructed agreement involving some parties, a public party, and private parties to construct, renovate, maintain, manage, or operate a project that serves the public and private needs. Some refer to it as a method for project funding, which can help overcome the public party's economic limitations via direct capital investment from the private parties in service establishment (Alinaitwe & Ayesiga, 2013). PPP was mainly observed to tackle the public budget burden in delivering the needed social services and infrastructures (Li et al. 2005). In addition, these agreements aim to share risks and investments between the collaborated parties, which can have significant benefits and achievements for each party. Nevertheless, PPP has also offered the chance for private sectors to contribute to long-term agreements through the public sectors to sell their services and make profits in the long run, especially with the stable demand for public services.

The need for mega infrastructure has increased over the last few decades due to the dramatically growing population living in big cities. Simultaneously, it may be hard for available infrastructure funds to meet the public needs with the growing demand. Building new infrastructures and maintaining existing others face insufficient public funds globally (Yun et al., 2009). Hence, the adoption of PPP agreements may be necessary to overcome these challenges. PPPs can overcome the public party's limitations in delivering services to the public. Not only that, but also redirect available public funds into more exceptional achievements for the nation. According to (PPIAF, 2016), the implementations
of PPP have been increasing over the last few years, which clearly indicates the importance of such contracts and approaches to developing societies.

On the other hand, designing a concession for PPP agreements is a complicated process due to the number of variables that need to be considered, which can affect all the participants in the concession agreement. The concession has many parameters and components, and a change in one component will considerably impact other components. The determination of the fair values of the concession components needs to be based on mutual benefits between the concession participants. The concession participants have different parts in the development of the concession; hence, they have different perspectives and goals. Therefore, the concession design needs to be constructed to balance the interests of the involved parties to ensure a smooth and sustainable development of the project.

The first phase of this dissertation aims to build a Socio-Economic System Dynamic (SD) model to facilitate the decision-making process for PPP projects. The model should help determine and assess the adequate concession period, concession price (user-payment), government subsidy, and capital structure (private and public equities). Also, a Socio-Economic Sustainability indicator will be provided to assess the Sustainability Performance of the given case studies. The model proposed in this phase provides a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects.

The second phase of this dissertation aims to build a Socio-Economic Multi-Objective Optimization (MOO) model to help determine the optimal concession values. It should provide possible values for several concession factors (concession period and price, government subsidy, and capital structure). Also, a Socio-Economic Sustainability indicator will be provided to assess the
Sustainability Performance of the given case studies. Having these contribution options can facilitate the decision-making process for both the public and private parties. The proposed model aims to optimize the values for the different concession variables when they are dependent on each other.

1.2 Problem Statement

One of the most significant aspects of successfully implementing PPP schemes is the adequate identification and balance between the involved parties' interests (Ng et al., 2012; Boyer & Newcomer, 2015; Gupta et al., 2013; Gordon et al., 2013; Wibowo & Alfén, 2015; Hwang et al., 2013; Wang, 2015). With the expansion of PPP developments in addition to the participation of private parties, there has been a tremendous encounter for the public sector to cope with, which can be seen in the principle-agent theory, due to the different perspectives of the involved parties (Gordon et al., 2013; Wang & Liu, 2015; Poulton & Macartney, 2012; Keser & Willinger, 2007; Saam, 2007; Müller & Turner, 2005; Shrestha et al., 2016). The public party objects to advancing social welfare, whereas the private sector is seeking investment sustainability and maximizing profits. When accomplishing and balancing benefits among the involved sectors, principle-agent can be tackled (Khmel & Zhao, 2015; Kurniawan et al., 2015; Hwang et al., 2013). Usually, private parties may act on their interests and may not do what is best for the public party unless their interests are satisfied. According to the principle-agent theory, the contract must be constructed to balance the interests of the involved parties to achieve positive incentives from all involved parties (Gordon et al., 2013; Müller & Turner, 2005).

Many attempts have been conducted to optimize one aspect or another in the PPP implementation development. However, most of the studies focused only on one or two concession
variables to optimize, while PPP projects have many concession variables that differ from one another. Besides, optimizing one variable may reduce the optimal values for other variables. This thesis aims to build models to optimize several different concession variables simultaneously. The following concessions items’ determinations and optimizations will be investigated in this thesis, Concession Period and Price, Government Subsidy, and Capital Structure. Also, a Socio-Economic Sustainability indicator will be provided to assess the Socio-Economic Sustainability Performance for the given case studies.

### 1.2.1 Concession Period and Price

The main aim of selecting the concession period and price is to ensure a suitable revenue for private sectors to recover their capital investment (Shen et al., 2002). In most PPP cases, a twenty to forty years concession period guarantees an adequate cash flow for the development costs repayment. This period depends on some economic and project factors, including the project type, concession price, and the potential generated revenue. Therefore, it can be a complicated decision-making process (Ullah et al., 2016). Private sectors may require long concession periods to reap enough revenue by collecting user payments in most cases. In contrast, the public sector may require shorter durations to protect the public's interest.

Practically speaking, the public party may determine the concession period before assigning the project to private parties (Zhang, 2009). The public parties may be focusing on maximizing social welfare, while the private parties may be focusing on maximizing their profits. Therefore, the decision for the concession period may be a complicated process. For example, public parties may have to issue large subsidies or large concession prices by minimizing the concession period, increasing their initial capital expenses, or decreasing social welfare. Therefore, balancing the levels of the concession
period, fee, and subsidies may be a critical decision process. From the private sector's perspective, collecting more profits could be accomplished with a high concession price, low demand volume, or low concession price and high demand volume. Therefore, a conflict of interest between the involved parties may be observed, and all parties should work together to balance their interests in the concession agreement.

On the other hand, concession prices should be selected carefully by considering the public interest. The concession price is typically determined based on the society's average per capita income to meet the public needs while ensuring an adequate users flow to increase the cash flow for generating the project's revenue. It can be clear that the concession period and the concession price have an inverse relationship.

Choosing the ideal concession period and price is complex, and it depends on several concession factors and components that may differ from one project to another. The concession price should be adequate to cover the private party’s investment in short concession periods. At the same time, it should be small enough to preserve the public's welfare and ensure an adequate users-flow. Alternatively, the concession period value should be sufficient to ensure the payback of the private investments plus a satisfactory profit is accomplished with a low concession price. At the same time, it should be short enough to ensure the public's interests and social welfare are protected.

Determining the right value of the concession period and price will affect other related factors and concessionary items in the PPP contract. For instance, reaching an optimal value for the concession period will reduce the optimal values of the other concession factors. Therefore, a tool that considers several PPP concession factors is needed due to the conflicting interests between these factors.
1.2.2 Capital Structure

The capital structure can be seen in the financing combination of the project between debt and equity, which can indicate the total capital cost and the value of the project. Optimizing the capital structure can have great benefits that can be seen in minimizing the capital cost and maximizing the project's value. Both public and private sectors may agree on an adequate equity level that satisfies each party of the involved parties (e.g., equity holders or shareholders, the public sector, and the lenders). Determining the level of equity is critical in defining the project's capital structure. Nevertheless, it is a challenging task due to the different views and requirements of the involved parties.

The ideal sharing ratio can be enhanced when all the involved parties balance their interests respectfully to their contribution to the actual contract. Where the public parties seek to smoothly implement the project sustainably with preserving public funds as much as possible, private parties' interests must be met to ensure the continuous progress of PPP projects.

However, optimizing the capital structure alone can negatively affect the concession components, such as concession period and price, due to the conflicting interests between the concession components.

1.2.3 Public Subsidy

Most of the projects operated under the PPP agreements make low profits due to the considerable current and future risks associated with such projects' long lifespan. Governments or public sectors should provide adequate subsidies for such poor profitability projects to make the project economically feasible for private sectors (Song et al., 2018; Wang, Cui, & Liu, 2018). These subsidies are essential due to the promising benefits of such low profitability projects to society's
sustainable development. In other words, from the private sector's perspective, the needed infrastructure projects for social development may not see the light if the projects have no potential return on investment. Therefore, financial supports from the public parties, such as subsidies and guarantees, are essential to attract private parties due to the PPP's long lifespan and the risks that may be associated with its uncertainties (Khmel & Zhao, 2015; Chen et al., 2012; Kokkaew & Wipulanusat, 2014; Shaoul et al., 2012).

The key goal of public parties is maximizing social welfare and adequately delivering the required infrastructures. It can be clear that public subsidies have an inverse relationship with the concession period and the concession price. The more value of subsidies issued by the public parties to the concession, the less period and price the concession will require to pay back its investments. Therefore, government subsidies may act as an effective tool to decrease the concession period and price. Alternatively, public parties can reduce their initial financial contribution to the project by elongating the concession period or by increasing the concession price.

It can be clear that the public parties' subsidies are used to attract more private parties and enhance competitiveness. However, preserving public funds and budget is as critical as attracting the participation of private sectors. Therefore, a tool that can balance all the involved parties' interests is vital in the scope of PPPs.

Public subsidies can be seen as a risk-sharing mechanism to balance both parties' interests (Wibowo et al., 2012). However, determining the adequate amount of Subsidy is the challenging part. The Subsidy should be large enough to cover the potential losses that private sectors may face and to act as a leverage tool for the public parties to increase such participation and competition of the private parties. Furthermore, at the same time, it should be small enough to preserve the public budget and social welfare. Determining the right amount of Subsidy will affect other related factors
in the PPP contract. For instance, reaching an optimal amount of government subsidy will reduce the optimal value of other factors. Therefore, a tool that considers several PPP concession factors is needed due to the conflicting interests between elements.

1.2.4 Sustainability Performance

Although PPP projects are usually mega projects in their nature and are constructed over a very long lifespan, the concept of sustainable development is barely touched in such projects (Hueskes et al., 2017). Thus, this may lead the agreements to only acquire short-term profits instead of long-term profits applicable to all the sustainability dimensions.

Usually, the most focused dimension when dealing with PPP projects is the economic dimension, where all shareholders emphasize the project's financial sustainability (Bennett, 1998). Hence, this is to ensure that the initial capital investment is paid back with the expected profits. From the sustainable economic perspective, PPP can be seen as a way of delivering infrastructures to achieve the sustainable development growth needed when governments do not have enough funds. Therefore, this may be very helpful, especially for developing countries where they can meet their sustainable growth development by utilizing private investments and capital. PPP can also be seen as new business prospects for the private parties to invest and profit. Hence, private sectors may have the ability to improve their sustainable economic development by undertaking PPP projects.

Yet, there is a clear need for quantitative methods to address the sustainability performance of PPP projects. These quantitative methods need to take all the PPP participants' contributions and expected outcomes into account to examine better and improve the sustainability performance outcomes. Because the participants' contributions to the PPP projects, which can be seen in investment distributions, risk allocations, public subsidies, etc., have a substantial impact on the
concession aspects and the economic and social sustainability performance of such projects. Every participant in the PPP agreement has different goals and expectations. Hence, taking these expectations into account and applying them to the long-term agreement may result in better sustainability performance for the PPP projects.

1.3 Research Objective and Contribution to the Body of knowledge

Public-Private Partnerships (PPP) have many critical socioeconomic 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. Therefore, assessing the dynamic and interdependent relationships between the socioeconomic 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. Hence, the first phase of this dissertation aims to build a novel socioeconomic SD model to facilitate the decision-making process for PPP projects. It should assess the adequate concession period, concession price (user-payment), government subsidy, and the capital structure (in the form of private and public equities). The model proposed in this phase gives a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects.

On the other hand, PPP is a long-term commitment involving several parties, including public sectors, private sectors, and lenders. When designing the concession, all parties’ interests must be satisfied to have a robust relationship between the involved parties. Their interests must be balanced optimally according to their contribution to the project, avoiding costly renegotiations or project
failures. Besides, optimizing interests between the involved parties may require some trade-offs. Therefore, the goal of the model presented in the second phase of this thesis is to help determine the optimal contribution ratios from each party by providing a series of feasible contribution options for several concession factors (concession period and price, sustainable performance, government subsidy, and capital structure). Having these contribution options can facilitate the decision-making process for both the public and private parties. The main aim of the second phase of this thesis is to build a multi-objective optimization model to maximize the benefits of each of the involved parties in the PPP concession agreement. The model will contain several concession variables, including Concession Period and Price, Public Subsidy, Public Equity, Private Equity, and the Sustainability Indicator. The proposed model aims to optimize the values for the different concession variables when they are dependent on each other. After that, the model will present different concession options containing different values for each of the concession components to help facilitate the decision-making process based on quantitative analysis.

1.4 Research Questions

The proposed models will try to simultaneously answer the following research questions for designing the concession agreement:

1. What is the optimal Socio-Economic sustainable value for the concession period when it is related to the optimal Socio-Economic sustainable values of the concession price, public equity, private equity, and public subsidy?
2. What is the optimal Socio-Economic sustainable value for the concession price when it is related to the optimal Socio-Economic sustainable values of the concession period, public equity, private equity, and public subsidy?

3. What is the optimal Socio-Economic sustainable value for the public equity when it is related to the optimal Socio-Economic sustainable values of the concession period, concession price, private equity, and public subsidy?

4. What is the optimal Socio-Economic sustainable value for the private equity when it is related to the optimal Socio-Economic sustainable values of the concession period, concession price, public equity, and public subsidy?

5. What is the optimal Socio-Economic sustainable value for the public subsidy when it is related to the optimal Socio-Economic sustainable values of the concession period, concession price, and the private and public equities?

6. What concession component has the major influence on the PPP Socio-Economic Sustainability Performance?

1.5 Research hypothesis

The research will also investigate the following hypothesis:

- **H1:** When designing the PPP concession, there is a direct relationship between the Private Equity and the Socio-Economic Sustainability Performance of PPP projects.

- **H2:** When designing the PPP concession, there is an inverse relationship between the Public Equity and the Socio-Economic Sustainability Performance of PPP projects.
• **H3**: When designing the PPP concession, there is an inverse relationship between the Concession Price and the Socio-Economic Sustainability Performance of PPP projects.

• **H4**: When designing the PPP concession, the Concession Period is the most influential component on the Socio-Economic Sustainability Performance of PPP projects.

### 1.6 Dissertation Structure

The dissertation is constructed in five chapters, as shown in Figure 1.

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*Figure 1. Dissertation Organization.*
CHAPTER 2: LITERATURE REVIEW

2.1 Introduction and Definition

Public-Private Partnerships (PPP) may be seen as constructed agreements involving some parties, a public party, and private parties to construct, renovate, maintain, manage, or operate a project that serves the public and private needs. Some refer to it as a method for project funding, which can help overcome the public party's economic limitations via direct capital investment from the private parties in service establishment (Alinaitwe & Ayesiga, 2013). Governments look at PPPs as a resource for initiating venture plans that would not be conceivable within the existing public party's fund. PPP was mainly observed to tackle the public budget burden in delivering the needed social services and infrastructures (Li et al. 2005). In contrast, PPPs should be implemented to restructure procurement methods and infrastructure deliveries (WorldBank, 2009). Remodeling and restructuring the public parties to meet the market demand was also emphasized as one of the PPP approach features (Ahmed & Ali, 2006; Hellowell, 2013; Valila, 2005).

By having these contracts, the public party can maintain ownership of the project; however, the private party may invest its capital to design, build, maintain, operate, or manage it. These agreements aim to share risks and investments between the collaborated parties, which can have significant benefits and achievements for each party. With PPPs, the public party remains responsible for delivering the project to the public due to its obligations to the public interest. On the other hand, by participating in these agreements, the private party can profit in the long run. It can be clear that the core target for the public party is to deliver sustainable public services and infrastructures, while the main goal for the private sector is to make profits.
PPPs can overcome the public party's limitations in delivering services to the public. Not only that, but also redirect available public funds into more exceptional achievements for the nation. The need for mega infrastructure has increased over the last few decades due to the dramatically growing population living in big cities. Simultaneously, it may be hard for available infrastructure funds to meet the public needs with the growing demand. Building new infrastructures and maintaining existing others face insufficient public funds globally (Yun et al., 2009). Hence, the adoption of PPP agreements may be necessary to overcome these challenges.

According to (PPIAF, 2016), the implementations of PPP have been increasing over the last few years, which clearly indicates the importance of such contracts and approaches to developing societies. Therefore, the public party's participation should be reformed to implement the right regulations and strategies for PPP rather than constructing the needed infrastructures due to the growing number of PPP projects (Sarmento & Renneboog, 2016; Chatterjee & Mahbub, 2011; Wang, 2015).

PPPs description may be classified into; a long-term relationship designed for long-term infrastructure projects containing pre-identified requirements to be met, a means of social and economic sustainable development, and a means of sharing risks between the parties delivering public services through an institutionalized collaboration.

Several authors have also highlighted the PPP procurement approach as a multi-dimensional approach where it contains several factors, including collaboration, mutual benefits and risks, durability, and sustainability (Sarmento & Renneboog, 2016; Shaoul et al., 2012; Martins et al., 2011; Kokkaew & Wipulanusat, 2014; Janssen et al., 2016; Villalba & Liyanage, 2016).

Neither the PPP concept is systematically well recognized worldwide, nor is the actual terminology of PPP. The name of this procurement approach, for example, can be seen as the Private Finance
Initiative (PFI) in the United Kingdom. Moreover, Private Sector Participation terminology is utilized in the development banking divisions. Many countries have their terminologies when it comes to PPP. For example, in the USA, P3 is widely used to refer to PPP. Some researchers refer to PPP's terminology as a ‘fashionable word’ (Bovaird, 1984; Kettner & Martin, 1986), while others refer to it as an attractive terminology used by the public sectors (Greve, 2003).

Nonetheless, Public Private Partnerships (PPP) terminology may act as the umbrella of many other terminologies where it can cover all the aspects related to the relationships between the involved parties. Moreover, the different PPP implementation techniques from one country to another and one public sector to another have more complicated creating a generally recognized definition (Liu et al., 2015).

To make the PPP agreements successful, PPPs should be originated by the public party, embrace specific project descriptions, highlight risk allocation among the participated parties, be limited through a contract, has a specified time frame, and has an apparent discrepancy between the involved parties (Thomson, 2005). For PPPs to succeed, we need to implement a robust contract mechanism that considers full details of the project's development, penalties associated with the contract, and the delivery and handover mechanism. We also need to consider the procurement methods used when assigning work under such agreements. Not to mention the vital role of a solid understanding of the legality, contract, finance, methods used, associated risks, and potential profits. Each project should undertake an enormous assessment before offering to bidders. The lifecycle cost, efficiency, value engineering, and risk analysis must all be considered before assigning work to bidders. All of that is a must due to the projects' long lifespan associated with the PPP approach.

One of the most significant aspects of successfully implementing PPP schemes is the adequate identification and balance between the involved parties' interests (Ng et al., 2012; Boyer &
Newcomer, 2015; Gupta et al., 2013; Gordon et al., 2013; Wibowo & Alfen, 2015; Hwang et al., 2013; Wang, 2015). With the expansion of PPP developments in addition to the participation of private parties, there has been a tremendous encounter for the public sector to cope with, which can be seen in the principle-agent theory, due to the different perspectives of the involved parties (Gordon et al., 2013; Wang & Liu, 2015; Poulton & Macartney, 2012; Keser & Willinger, 2007; Saam, 2007; Müller & Turner, 2005; Shrestha et al., 2016). The public party objects to advancing social welfare, whereas the private sector is seeking investment sustainability and maximizing profits. When accomplishing and balancing benefits among the involved sectors, principle-agent can be tackled (Khmel & Zhao, 2015; Kurniawan et al., 2015; Hwang et al., 2013). Usually, private parties may act on their interests and may not do what is best for the public party unless their interests are satisfied. According to the principle-agent theory, the contract must be constructed to balance the interests of the involved parties to achieve positive incentives from all involved parties (Gordon et al., 2013; Müller & Turner, 2005). Besides, preference theory highlights the balancing of interest among the involved parties to achieve better outcomes (Ke et al., 2010; Ng et al., 2007; Stasiukynas, 2011; Fernandes et al., 2015).

When considering the public investment, the public party should use the available resources efficiently (Hanák & Muchová, 2015). For example, when assigning infrastructures, lifecycle costs, including designing, constructing, operating, and maintaining the infrastructures, should be examined, assessed, and compared to all other possible constructing alternatives to choose the lowest and most cost-efficient option (Shen et al., 2006; Daito & Gifford, 2014; Mota & Moreira, 2015; Iseki & Houtman, 2012; Sarmento & Renneboog, 2016). Despite that, practically speaking, this is not the case in most countries. Whereas on the construction basis, the use of lifecycle cost analysis in the public party is limited (Hanák & Muchová, 2015; Heralova, 2014). The contractors may be usually nominated based on the lowest bid neglecting the most cost-efficient option. Even if the proposal
contains a multi-criteria assessment, the price usually plays the dominant factor in the bid selecting process (Tamosatiene et al., 2013; Zavedskas et al., 2010).

PPPs’ demand is growing all over the world. However, no systematic examination could be implemented to allocate the success and failure factors of such projects (Alinaitwe & Ayesiga 2013). We can better understand how managing such projects can be enhanced with more efficiency by having these factors. One way to successfully implement PPP is for governments to develop legislative frameworks that would regulate partnerships and permit foreign ownership, for example, of the needed assets. Developing the framework will require a robust understanding of PPPs implementation's theoretical and numerical characteristics.

Some previous research papers examined the implementation improvements of PPPs qualitatively and quantitatively. Many previous studies highlighted the importance of optimizing different concessionary components (Carbonara et al., 2014; Sarmento & Rennebog, 2016; Chou et al., 2012; Bednarek et al., 2012; Ng et al., 2007; Ke et al., 2008; Kurniawan et al., 2015; Wang, 2015; Wang & Liu, 2015; Shen et al., 2016; Xu et al., 2012; Niu and Zhang, 2013; Peng et al., 2014; Feng et al., 2018; Sharma et al., 2010; Lomoro et al., 2020; Yun et al., 2009; Scandizzo and Ventura, 2010; Soumaré and Lai, 2016; Jasiukevičius and Vasiliauskaitė, 2012). Many of the attempts mentioned above have been conducted to optimize one aspect or another in PPP implementation development. However, most of the studies focused only on one or two variables to optimize, while PPP projects have many variables that differ. Besides, optimizing one variable may reduce the optimal values for other variables.

PPP has many critical socioeconomic 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. Therefore, assessing the dynamic and
interdependent relationships between the socioeconomic 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. Hence, the first phase of this dissertation aims to build a novel socioeconomic 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 private and public equities). The model proposed in this phase gives a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects.

On the other hand, PPP is a long-term commitment involving several parties, including public sectors, private sectors, and lenders. When designing the concession, all parties’ interests must be satisfied to have a robust relationship between the involved parties. Their interests must be balanced optimally according to their contribution to the project, avoiding costly renegotiations or project failures. Besides, optimizing interests between the involved parties may require some trade-offs. Therefore, the goal of the model presented in the second phase of this thesis is to help determine the optimal contribution ratios from each party by providing a series of feasible contribution options for several concession factors (concession period and price, sustainable performance, government subsidy, and capital structure). Having these contribution options can facilitate the decision-making process for both the public and private parties. The main aim of the second phase of this thesis is to build a multi-objective optimization model to maximize the benefits of each of the involved parties in the PPP concession agreement. The model will contain several concession variables, including Concession Period and Price, Public Subsidy, Public Equity, Private Equity, and the Sustainability Indicator. The proposed model aims to optimize the values for the different concession variables
when they are dependent on each other. After that, the model will present different concession options containing different values for each of the concession components to help facilitate the decision-making process based on quantitative analysis.

2.1.1 History of PPP

PPPs origin is a controversial subject, depending on the terminology and the application of such a procurement approach. Some traced the origin of PPP to the Roman Empire and the Elizabethan eras when private people like Apostle Matthew used to collect taxes in the best interests of the Roman public. In addition, the history of implementing PPPs can be classified by the following centuries:

In the 15th century:

- Private parties provided the military with arms for Sir Francis Fleet (Hodge & Greve, 2007).

In the 17th century:

- The UK was one of the first to implement the PPP procurement approach for infrastructure projects (Auriol & Picard, 2013; Parker & Hartley, 2003).
- The Dutch government partnered with private parties to meet the increased demands for infrastructure development when they faced extreme challenges with the available public budget to meet the required infrastructure development (De Vries & Yehoue, 2013).
- PPP was implemented in the USA to build the Philadelphia and Lancaster Turnpike Road in Pennsylvania (Buxbaum, 2009; De Vries & Yehoue, 2013). Most of the US's Turnpike projects were carried out by the private parties entirely, while a few others received some public support.

In the 18th century:
The UK started the industrial revolution, and there was an increased demand for private parties' participation. Mega infrastructure projects such as the Mersey water connection between Manchester and Liverpool were established (Arnold & McCartney, 2008). In addition to the mega railway infrastructure projects, the private sector invested heavily in development (De Vries & Yehoue, 2013).

Many European countries, including France and Germany, started to follow the UK's steps by implementing PPP contracts (Sambrani, 2014; Skietrys & Raipa, 2009).

In the 19th century:

The implementation of PPP projects has then grown worldwide with the spread of the neoliberal ideologies in the late 1980s, as there was a need to assess and optimize the public's interests in the PPP approach (Shaoul et al., 2012; Babatunde et al., 2015; Morales et al., 2013). They recognized that meeting the infrastructure demand could not be achieved by utilizing the public's funds, and there was a need for the private sector's participation (Dunn-Cavelty & Suter, 2009; Zhang, 2014).

Some authors claim that the PPP’s origin was first introduced by the US in the late 19th century (Fosler & Berger, 1982), while others referred it to the UK when the PFI was initiated in 1992 (Ghobadian et al., 2004; Bing et al., 2005).

Furthermore, the PFI can be the first systematic approach to encourage the private parties' participation. The PFI's primary purpose is to ease the public's budget's burden in developing the needed infrastructures by utilizing the private parties' involvement. After that, many countries worldwide started to duplicate the UK PFI by creating systematic forms and legislation regarding PPP implementations.
2.1.2 Motivation Factors

Due to the growing demand for constructing new infrastructures and renovating existing infrastructures, the public parties and governments found it difficult to meet this increasing demand with the available public funds. Hence, the cooperation with the private sector to facilitate the infrastructure needs delivery. It can be a challenge for the public parties to meet the growing demands with the available public funds (Olalekan & Hashim, 2014; Sambrani, 2014; Desgrées, 2012; Gordon et al., 2013; Sharma, 2007; Carbonara et al., 2014; Hwang et al., 2013; Wojewnik-Filipkowska & Trojanowski, 2013; Poulton & Macartney, 2012; Gouveia & Raposo, 2012; Percoco, 2014; Harada & Ogunlan, 2015; Liu et al., 2015; De Jong et al., 2010; Martins et al., 2011; Sarmento & Renneboog, 2016; Grubišić Šeba et al., 2014; Shen et al., 2006). In ideal situations, governments tend to tackle this challenge by borrowing money. However, the level of debt is rising in several nations, and borrowing may not be suitable for meeting the increasing demand for infrastructures. Therefore, the private sector's participation may be a must to tackle the government's budget deficit by providing substantial capital. With the financial support and funds from the private parties, public parties may not have the full financial responsibilities for carrying the required infrastructures to the society. The public party will share the required capital investments with the private sector in developing services. Not requiring significant initial investments may ease the burden of the public parties' annual budget by delivering the necessary services without the need to borrow money, where the PPP procurement approach may be seen as a means of addressing public fiscal limitations (Sarmento & Renneboog, 2016; Moro Visconti, 2014; Gouveia & Raposo, 2012). With the public budget constraints, PPPs may be seen as the only option for governments to deliver the required services while avoiding borrowing
limitations. Accessing private parties’ capital investments may be a part of the integral attributes of the PPP procurement approach.

Another motivation factor for the public parties participating in PPP projects is the risk-sharing opportunity (Sharma, 2007; Roehrich et al., 2014; Alexandersson et al., 2008; Jin & Zhang, 2011). Public parties can transfer from full risk responsibilities to sharing some potential risks with private parties.

Improving efficiency is another reason why the public sector should involve in the PPP agreements. The efficiency that the private sector can bring to the table is higher than the public sector’s efficiency (Čiarnienė & Vienažindienė, 2005; Mota & Moreira, 2015).

Working capacity can be seen as another reason for the public parties to seek the participation of the private sectors (Sambrani, 2014). Not to mention the vast experience and technological innovations private sectors can provide.

On the other hand, there is a lack of literature outlining the outcomes and the incentives of the private party participation in the PPP procurement approach. Hence, the private party’s involvement in such projects can be evaluated for their outcomes and incentives for participating in regular projects. Generally speaking, PPP has offered the chance for private sectors to contribute to long-term agreements through the public sectors to sell their services and make profits for the long run, especially with the stable demand for public services. Participating in PPP contracts with the governments may have a minimum risk to the private sectors if accompanied by certain guarantees from the public parties. Therefore, from the private parties’ perspective, participating in PPP developments can be attractive for those who seek low profitability but long-term stable revenue stream with minimal risks involved. It can be clear that the primary motive for private parties’
participation is making profits. Hence the need for a quantitative model to balance their interests is required.

### 2.1.3 Financial Aspects of PPP

The PPP projects’ financial structure can be seen as the financial resources needed to develop the project, which are generally paid back from the project’s revenue. Therefore, the stream of revenue and the project's assets for the required project will play an essential part in determining the project's debt capacity, unlike the examinations of the financial credits and the total portfolio in corporate finance. For the PPP project, this can be challenging because during the construction period, the project may not obtain any revenue, and the revenue stream will only start in the operation period. Therefore, long-term financial tools will be needed to handle the costs at the primary phases of the project until the project enters the operation stage and begins generating sufficient revenue.

The PPP developments’ Financing cost may act as the utmost vital aspect of the development. There is a robust connection between the financing cost rate of the project, the financing efficiency, and the investment’s return rate, which can essentially affect the public party's decision (Tao & Ji, 2015). For example, in the UK, the increased risks linked to PPP developments can be related to the increased financial costs and the lack of equity funds and short-term debts (Demirag et al., 2015). Therefore, the public sector should achieve more participation from the private parties in debt investment and equity sharing.

PPP projects funds can be seen in three different forms: public fund (which is provided by the public party as a grant), dept (which can be provided by public or commercial banks), and equity (which can be seen by the pure capital invested in the project). Sometimes, there is a fourth source of funds in developing countries, which can be seen in the international loans that international
lenders provide. Furthermore, government subsidies and public bonds play an essential role in PPP project financing. When designing the optimal capital structure between the involved parties, all these financial resources must be considered respectfully.

Financial supports from the public parties, such as subsidies and guarantees, are essential to attract private parties due to the PPP's long lifespan and the risks that may be associated with its uncertainties (Khmel & Zhao, 2015; Shaoul et al., 2012; Chen et al., 2012; Kokkaew & Wipulanusat, 2014).

The public parties usually provide two forms of guarantees to overcome these challenges: revenue guarantee and loan repayment guarantee. Revenue guarantees that could be characterized by trigger variables (the threshold of the guarantee) and the compensation approach (which can be seen in payments, subsidies, or concession period extensions) (Asao et al., 2013). The threshold considers the annual income, the total income, and the internal rate of return. The public party's reimbursement occurs when a trigger variable surpasses the pre-agreed-upon minimum edge. Adequate compensation is then selected by the public sectors depending on the given situation. On the other hand, a loan repayment guarantee may attract investors who have less financing costs than private capital (Kurniawan et al., 2015; Zhang, 2014).

It may be worth mentioning that public parties, on the other hand, may be eligible to acquire any extra revenue the private parties may obtain. The factors for defining the excess revenue's ideal sharing ratio were evaluated by Wang and Liu (Wang & Liu, 2015).

The ideal sharing ratio can be enhanced when all the involved parties balance their interests respectfully to their contribution to the actual contract. Where the public parties seek to smoothly implement the project sustainably with preserving public funds as much as possible, private parties’ interests must be met to ensure the continuous progress of PPP projects.
Other forms of guarantees are also considered by the public sector, including; price adjustment, which ensures adequate profitability is gained by the private parties (Qiu & Wang, 2011; Xu et al., 2012), tax relief which reduces the overall cost burden by exempting investors from paying specific amounts of taxes (Chen et al., 2012), a restrictive competition which tackles the potential monopolies contracts may have (Martins et al., 2011; Sarmento & Renneboog, 2016), a land lease which can be seen in the allocation of lands to be used for executing the projects (Chen et al., 2012), and the potential change in currency and interest rates (Du & Li, 2008; Hanaoka & Palapus, 2012).

It can be clear that the public parties’ guarantees are used to attract more private parties and enhance their competitiveness. However, preserving public funds and budget is as critical as attracting the participation of private sectors. Therefore, a tool that can balance all the involved parties' interests is vital for developing PPPs' scope.

2.1.4 Advantages and Disadvantages of PPP

According to several previous studies, Public-Private Partnership has many advantages over other types of agreements and approaches, and these advantages can be seen in; delivering projects for the society when the public party or government does not have enough funds to design, build, operate, and maintain such projects (Hwang et al., 2013; Gouveia & Raposo, 2012; Carbonara et al., 2014; Desgrées, 2012; Gordon et al., 2013; Liu et al., 2015). Besides the higher project efficiency and project delivery that private sectors can bring onto the table, due to the full experts and abilities private parties have. (Miller 1999; Miller et al. 2000) claimed that public projects could be enhanced when privatized according to some factors, including; the more efficient and less bureaucratic nature that private sectors have over public sectors, the more funds that private sectors can provide for projects when the public sector has budget limitations, the more utilization for innovative technologies,
expertise, and managerial skills private sectors have, and the increased competition for projects related with the private parties’ involvement. Not to mention sharing risks that are associated with building mega infrastructures. When the private sector shares risks, they might be more careful handling projects, and they may do their best in risk analysis and control even if they would have to put more money in advance to mitigate these risks.

Many scientists have studied and highlighted the advantages and disadvantages of the implementation of PPPs (Carbonara et al., 2014; Andreas et al., 2016; Poulton & Macartney, 2012; Wojewnik-Filipkowska & Trojanowski, 2013; Desgrées, 2012; Sharma, 2007; Gordon et al., 2013; Harada & Ogunlan, 2015; Liu et al., 2015; Martins et al., 2011; Sarmento & Renneboog, 2016; Shen et al., 2006; Hwang et al., 2013; Olalekan & Hashim, 2014; Gouveia & Raposo, 2012; Percoco, 2014; Sambrani, 2014). They have emphasized that the primary advantage of the PPP procurement approach for public parties is avoiding public budget limitations. With the financial support and funds from the private parties, public parties may not have the full financial responsibilities for delivering the required infrastructures to society. The public party will share the required capital investments with the private sector in developing services. Financial investments in PPP do not require an initial large capital fund. Instead, small funds will be carried out along the period of the concession (Shen et al., 2007; Liu et al., 2015), which sequentially may limit the infrastructure’s delays that can arise through the construction phase of the project’s development (Shen et al., 2006; Yang et al., 2010). Not requiring significant initial investments may ease the burden of the public parties’ annual budget by delivering the necessary services without borrowing money, where the PPP procurement approach may be seen as a means of addressing public fiscal limitations (Sarmento & Renneboog, 2016; Moro Visconti, 2014; Gouveia & Raposo, 2012). With the limits of public parties, PPPs may be seen as the only option for governments to deliver the required services, avoiding borrowing limitations. Financial
accessibility is a critical factor in the PPP procurement approach (Liu et al., 2015). Where public parties can get financial support from the private parties involved in such agreements, accessing private parties' capital investments can be seen as a part of the integral characteristic of the PPP procurement approach. Nevertheless, sometimes this is not the case, where some PPP agreements do not require a private party's financial investment (de Jong et al., 2010).

In contrast, public parties' long-term liabilities can potentially harm the public parties' budget sustainability eventually, as they are considered to have the same effects as borrowing money (Morales et al., 2013; Benito et al., 2008).

Furthermore, risk-sharing may represent another good factor of the PPP procurement approach (Jin & Zhang, 2011; Sharma, 2007; Alexandersson et al., 2008; Molen et al., 2010; Roehrich et al., 2014), where public parties can transfer from full risk responsibilities to sharing some of the potential risks with private parties. When the risks are shared, private parties have more experience handling the involved risks with all aspects and stages of implementing the project, hence dropping the overall expenditure of the developments. For example, the execution of the PPP approach in the school division in France helped save about 15% in capital costs compared to the other traditional approaches (World Bank, 2013). However, in some cases, this is not the case; for instance, implementing the PPP procurement approach for road construction may result in a 24% cost increase compared to other procurement approaches (Carmona, 2010). Also, many scientists argued that decreasing project costs might not be related to the participation of private parties (Gordon et al., 2013; Daito & Gifford, 2014; Clark & Root, 1999; Benito et al., 2008).

One of the most glaring weaknesses of PPPs is that with the utilization of the private party's capital funds, it may be harder to decrease the total costs of the development because of the higher amount of interest rates for the private parties borrowing funds (Alexandersson et al., 2008). Therefore, public
guarantees are needed to attract more competitive lenders and reduce the cost of the private party's borrowing funds.

Efficiency can be one more advantage of the choice of the PPP procurement approach. Using private parties' expertise in the field can improve the outcome efficiency of the projects and hence the public parties' dynamic growth. The efficiency that the private sector can bring to the table is higher than the efficiency of the public sector (Čiarnienė & Vienažindienė, 2005; Mota & Moreira, 2015).

Technological innovations can be seen as another advantageous factor emphasizing the choice of the PPP procurement approach, where public parties can access the knowledge and innovations of the private parties. Usually, when assigning PPP projects, the public party determines the required outcomes and deliverables of the projects rather than how the project should be constructed (Wang, 2014; Kurniawan et al., 2015; Villalba-Romero & Liyanage, 2016; Parker & Hartley, 2003). Therefore, there is room for private parties to provide innovative techniques and methodologies for project deliveries.

One of the most prominent disadvantages of PPP is the complexity of its procurement approach, which may result in a higher cost for the private parties to prepare a bid to enter a tender. Many scientists have highlighted the initial high cost required to enter a bid in PPP agreements (Xu et al., 2012; Schepper et al., 2014; Mu et al., 2011). This initial high cost of entering vendors because of the complicated process of the PPP procurement approach may decrease the number of private party participants.
2.2 Critical Concession Components Affecting PPP Projects

- Concession

A concession can be described as an agreement involving private parties and a public party for the private parties to exclusively construct, operate, maintain, and invest in a given public utility or a project for an agreed-upon number of years. This includes transferring responsibilities between the involved parties. During the concession period, the private parties can collect revenue directly from the users and public parties through subsidies or direct investments if the available income is not financially viable. Globally, concessions can be seen as the most acknowledgeable PPP arrangements (Xu et al., 2012; Carbonara et al., 2014). Usually, this occurs for large infrastructure projects that require a considerable budget and ability. The private party will be accountable for the financial obligations besides constructing and operating the project and collecting payments from users throughout the concession period (Tang et al., 2010).

- Concession Participants

The concession is an agreement containing three major players: public parties, private parties (the concessionaires), and financiers (the lenders) (Pantelias and Zhang, 2010).

1) The first player is the public sector, which has a substantial part in setting the required project's regulations, frameworks, and laws. The public party represents the public welfare and interest. Hence, they will be responsible for protecting the public interests through the adequate planning of the project development, including ensuring efficiency and obtaining the appropriate equity.

2) The second player is the private parties (the concessionaires) which can be described as the legal participants who obtain the right in investing, constructing, operating, maintaining, and managing
the required project, as well as collecting users’ payments during the period of the concession to recover their expenditures (Yu et al., 2014). Moreover, private parties may be a coalition party containing investors, designers, contractors, consultants, operators, and any other private sectors that may be needed to develop the required project.

3) The third player is the lenders, who have a significant part in developing the PPP projects through financing the required capital for the project. They will be providing long-term loans according to the evaluation of the debt service ratio for the project, which can be derived from the potential generated revenue and the lifecycle expenses of the project.

- **Concession design**

Designing a concession is a complicated process due to the number of variables that need to be considered, which can affect all the participants in the concession agreement. The concession has many parameters and components, and a change in one component will considerably impact other components. The determination of the fair values of the concession components needs to be based on mutual benefits between the concession participants. The concession participants have different parts in the development of the concession; hence, they have different perspectives and goals. Therefore, the concession design needs to be constructed to balance the interests of the involved parties to ensure a smooth and sustainable development of the project.

Many scholars proposed several effective concession design frameworks to successfully implement the concession of PPP. Zhang and Chen identified four stages that support implementing the concession design successfully: design of workable concessions, selection of competitive concessionaires, financial regulations of the selected concessionaires, and design of periodic re-concession and rebidding of concession (Zhang & Chen, 2013). Many studies emphasized the design
of workable concession due to its critical impact on setting the financial structure and allocation of risk schemes. It also refers to selecting important concessionary components and values that have the biggest impact on the lifecycle performance of the project.

The PPP concession should be attractive to private parties and investors to attract more participants. And the only way to make that possible is if the concession has a good return rate. Many scholars have investigated the financial performance of PPP concessions through different techniques, including the project payback period, net present value-at-risk (Ye, 2000), and cost-benefit analysis (ESCAP, 2003). Using these techniques rest on the actual net cash flow of the PPP development, neglecting some uncertainties that the project may face, such as the user-demand change or the change in interest or inflation rates. These uncertainties may considerably impact the project payback period (Malini, 1999). In addition, estimating the NPV or payback period may not be the safest step in initiating the concession agreement. It may lead to costly renegotiations with the occurrence of such uncertainties. Renegotiating the concession agreement from time to time could negatively impact the project's efficiency and may have considerable negative impacts on one or more participants in the concession agreement.

The private parties may have a mechanism in the concession agreement which allows them to increase the concession price if the generated revenue is smaller than the estimated revenue (Ngee, 1997). However, this will affect the public interests negatively as their interest is to keep the concession price at a lower level to meet social welfare. Once again, this may also lead to costly and lengthy renegotiations between the involved parties in the concession agreement. For instance, in 1995, when the private parties decided to increase the tolls for the Hong Kong Eastern Harbor Crossing, their proposal was rejected by the public party, which led them to almost two years of proceedings. Raising the concession price may also lead to decreased user demand; hence, less
revenue is generated for the project. Therefore, decision-making is complicated due to the multi variables associated with the concession.

### 2.2.1 Concession Period and Price

The concession period and price can be seen as two of the essential concessionary items in the PPP agreement. They can be the core parameters of the financial analysis for PPP projects. Besides, they will significantly determine the project's value and its expected future generated revenue. Usually, cash flow analysis is used to define the concession period and price for PPP projects; however, this method has some limitations regarding uncertainties associated with such large projects (Ng et al., 2007). Moreover, the main aim of selecting the concession period and price is to ensure a suitable revenue for private sectors to recover their capital investment (Shen et al., 2002). In most PPP cases, a twenty to forty years concession period guarantees an adequate cash flow for the development costs repayment. This period depends on some economic and project factors, including the project type, concession price, and the potential generated revenue. Therefore, it can be a complicated decision-making process (Ullah et al., 2016).

Private sectors may require long concession periods to reap enough revenue by collecting user payments in most cases. In contrast, the public sector may require shorter durations to protect the public's interest.

On the other hand, concession prices should be selected carefully by considering the public interest. The concession price is typically determined based on the society's average per capita income to meet the public needs while ensuring an adequate users flow to increase the cash flow for generating the project's revenue. It can be clear that the concession period and the concession price have an inverse relationship. For instance, the higher the concession price is, the less concession
period the project may require repaying its development investment. Moreover, on the contrary, if the concession price is set low by the public agencies for any reason, the project may require a more extended concession period to generate sufficient revenue. Or additional public support in the forms of subsidies or guarantees may be needed to cover the insufficient revenue stream.

Choosing the ideal period and price is complicated, and it depends on several factors that may differ from one project to another. The concession price should be large enough to cover the private parties’ investment in short concession periods. At the same time, it should be small enough to preserve the public's welfare and ensure an adequate users-flow. Determining the right value of the concession period and price will affect other related factors and concessionary items in the PPP contract. For instance, reaching an optimal concession period will reduce the optimal values of the other factors. Therefore, a tool that considers several PPP contract factors is needed due to the conflicting interests between factors.

The long-term concession period selection was examined in the literature (Rudžianskaitė et al., 2015; Ye & Tiong, 2000; Shen et al., 2002; Wu et al., 2011; Carbonara et al., 2014; Zhang, 2009; Wang et al., 2018; Yu & Lam, 2013; Yang et al., 2007; Roehrich et al., 2014; Bao et al., 2015; Shen et al., 2005; Peng et al., 2014; Ngee et al., 1997; Feng et al., 2018; Scandizzo & Ventura, 2010; Feng et al., 2019; Shen et al., 2007; Liou & Huang, 2008; Shen & Wu, 2005; Zhang & Abourizk, 2006; Yu & Lam, 2013; Shaoul et al., 2012; Zhang, 2011) and many more. Typically, the concession period lasts from twenty to thirty years (Wang, 2014; Cruz & Marques, 2013; Zhang, 2014; Qiu & Wang, 2011), and it may also be seen for a longer period that can go up to almost a century (Viegas, 2010).
Table 1. Concession Periods for some of the US. PPP Projects.

<table>
<thead>
<tr>
<th>PPP Project</th>
<th>State</th>
<th>Investment ($millions)</th>
<th>Concession Period (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The US I-495 Express Lanes</td>
<td>Virginia</td>
<td>2,068</td>
<td>80</td>
</tr>
<tr>
<td>The I-4 Ultimate</td>
<td>Florida</td>
<td>2,300</td>
<td>40</td>
</tr>
<tr>
<td>The IH-635 Lanes</td>
<td>Texas</td>
<td>2,600</td>
<td>52</td>
</tr>
<tr>
<td>The I-595 Roadway</td>
<td>Florida</td>
<td>1,800</td>
<td>35</td>
</tr>
<tr>
<td>The MLK Extension</td>
<td>Virginia</td>
<td>460</td>
<td>58</td>
</tr>
<tr>
<td>The Pocahontas Parkway</td>
<td>Virginia</td>
<td>597.4</td>
<td>99</td>
</tr>
<tr>
<td>The Dulles Greenway</td>
<td>Virginia</td>
<td>350</td>
<td>40</td>
</tr>
<tr>
<td>The North Tarrant Express</td>
<td>Texas</td>
<td>2,000</td>
<td>52</td>
</tr>
<tr>
<td>The Presidio Parkway</td>
<td>Texas</td>
<td>852</td>
<td>50</td>
</tr>
<tr>
<td>The South Bay Expressway</td>
<td>California</td>
<td>658</td>
<td>35</td>
</tr>
<tr>
<td>The Chicago Skyway</td>
<td>Illinois</td>
<td>1,830</td>
<td>99</td>
</tr>
<tr>
<td>The Indiana toll Road</td>
<td>Indiana</td>
<td>3,800</td>
<td>75</td>
</tr>
<tr>
<td>The SH-130</td>
<td>Texas</td>
<td>1,300</td>
<td>50</td>
</tr>
</tbody>
</table>

2.2.1.1 Optimizing Concession Period and Price

Practically speaking, the public party may determine the concession period before assigning the project to private parties (Zhang, 2009). The public parties may be focusing on maximizing social welfare, while the private parties may be focusing on maximizing their profits. Therefore, the decision for the concession period may be a complicated process. For example, public parties may have to issue large subsidies or large concession prices by minimizing the concession period, increasing their initial capital expenses, or decreasing social welfare. Therefore, balancing the levels of the concession
period, price, and subsidies may be a critical decision process. From the private sector's perspective, collecting more profits could be accomplished with a high concession price, low demand volume, or low concession price and high demand volume. Therefore, a conflict of interest between the involved parties may be observed, and all parties should work together to balance their interests in the concession agreement.

The Optimizing of the involved parties' benefits through optimizing the concession's period, price, and capacity was investigated by Guo and Yang (Guo & Yang, 2009). Tan et al. used a bi-objective model to analyze the private parties' behavior (Tan et al., 2010). Moreover, demand uncertainties were investigated to examine its impact on the concession period, price, and capacity (Niu & Zhang, 2013) and examine the flexibility of the BOT agreement (Tan & Yang, 2012).

Many researchers have investigated modeling the concession period via different approaches, including; the NPV calculations (Wu et al., 2011; Shen et al., 2002), game theories (Shen et al., 2005; Bao et al., 2015; Yang et al., 2007; Peng et al., 2014), besides simulation modeling (Feng et al., 2019; Ng et al., 2007(a); Ng et al., 2007(b); Feng et al., 2018; Wang et al., 2018; Carbonara et al., 2014; Zhang, 2009; Yu & Lam, 2013; Ngee et al., 1997; Scandizzo & Ventura, 2010).

The NPV considers the forecasting cash flow for the given project (Ye & Tiong, 2000). Shen et al. created a BOT tool for choosing the adequate concession interval to balance the involved parties' interests by describing the accumulated NPV curve (Shen et al., 2002). Yet, the proposed model neglected the net asset value and turnover requirements. Hence, another model was proposed, integrating the turnover and net asset value (Wu et al., 2011). This necessity suggestively attracts a good handover point for the public party.

Nevertheless, the game theory method has been used to control the concession period during the negotiation process between the involved parties. Negotiating the concession period is a dynamic
bargaining process (Shen et al., 2007). Every participant will be focusing on maximizing their interest until they at least reach a point that meets their basic expectations and requirements. This method can enhance the identification of a more exact concession span (Shen et al., 2007; Hanaoka & Palapus, 2012). Moreover, (Peng et al., 2014) introduced an option game tool to optimize the concession period and the public Subsidy for better PPP projects. They concluded that the elongated the concession period is, the less public Subsidy the project would require. Furthermore, Yang et al. proposed a Stackelberg strategic game tool to determine the best plans for public parties in the concession period and the private parties’ corresponding investment (Yang et al., 2007).

The uncertainties may impact the cash flow for the project and hence the concession period (Liou & Huang, 2008). However, introducing the simulation methods can help to take the impact of uncertainties into account. For instance, the introduction of the Monte Carlo simulation method helped in determining the adequate concession period based on different financial variables, including the NPV, concession price, discount rate, capital structure, revenue, and construction period (Zhang & Abourizk, 2006; Shen & Wu, 2005). Ng et al. created a tool to determine the less risky concession period for private parties by obtaining several potential options for the IRR (Ng et al., 2007(a)). The tool contributed by including the risk factors, which can be essential as it concluded that taking these risks into account could affect the choice of the concession period. The study then was further extended via an extended model, which can help in trading off three different concession variables (Ng et al., 2007(b)). The design of the concession period was also studied using different approaches such as the multiple linear regression (Ngee et al., 1997) and the decision support system method using Monte Carlo simulations (Yu & Lam, 2013).

Much quantitative research has been directed to inspect the influence of the concession period and price on PPP procurement development. The goal is to find an optimal contribution from each of
the involved parties, thereby gaining mutual benefit. For example, (Wang et al., 2018) proposed a stylized tool to elaborate on designing an optimized BOT contract, including government subsidy. They found that long concession periods are not always preferred by the private sectors, which can conflict with previous findings, which claimed that the private sectors benefit more from the most prolonged concession period (Niu and Zhang, 2013). (Feng et al., 2019), offered a quantitative model for the concession period optimization under some assumptions. The study aimed to introduce the influence of public equity and the time value for money into the quantitative model. Besides, (Feng et al., 2018) presented an optimization model to balance the interests of the involved parties. The model focused on optimizing the design for concession arrangements for user-pay projects. The model could produce some viable contract options to enhance the decision-making process.

Additionally, (Scandizzo and Ventura, 2010) proposed a model for concession contracts between the involved parties. The model was built under two conditions: dynamic uncertainties and the participated parties' strategic behavior. The model was conducted using the real options theory due to the uncertainty and irreversible consequences the contract may have.

Choosing the ideal concession period and price is complex, and it depends on several concession factors and components that may differ from one project to another. The concession price should be adequate to cover the private party’s investment in short concession periods. At the same time, it should be small enough to preserve the public's welfare and ensure an adequate users-flow. Alternatively, the concession period value should be sufficient to ensure the payback of the private investments plus an acceptable profit is accomplished with a low concession price. At the same time, it should be short enough to ensure the public's interests and social welfare are protected. Determining the right value of the concession period and price will affect other related concession components in the PPP contract. For instance, reaching an optimal concession period will reduce the
optimal values of the other components. Therefore, a tool that considers several concession factors is needed due to the conflicting interests between the concession's components.

2.2.2 Capital Structure

The capital structure may determine the project’s owners’ commitment to its future success. It can be measured by several indicators, including but not limited to debt-to-equity or assets-to-equity ratios. The capital structure can be seen in the financing combination of the project between debt and equity, which can indicate the total capital cost and the value of the project. In a sense, when a project has a substantial debt-to-equity ratio, this can indicate that the project is at a high risk of failure. For example, when a project faces a high debt ratio, which the shortage of capital funds may cause, it may be hard to meet the required loan repayments. Optimizing the capital structure can have great benefits that can be seen in minimizing the capital cost and maximizing the project's value.

Many theories have investigated the capital structure throughout the literature, such as the traditional capital structure (Durand, 1952), the Modigliani-Miller theory (Modigliani & Miller, 1958), the tradeoff theory (Kraus, 1973), the corporate control theory (Harris & Raviv, 1988), the agency cost theory (William & Michael, 1976). These theories are mainly utilized to determine and enhance the connection between the capital structure and the corporation’s value. For example, the Modigliani-Miller theory maximized the corporation value via the debt-to-equity ratio (Modigliani & Miller, 1958). However, these theories were studied under some optimistic and restrictive assumptions that may not reflect the practical implementations of the PPP projects.

2.2.2.1 PPP Project Finance

PPP projects funds can be seen in three different forms: public fund (which is provided by the public party as a grant), dept (which can be provided by public or commercial banks), and equity
(which can be seen by the pure capital invested in the project). Sometimes, there is a fourth source of funds in developing countries, which can be seen in the international loans that international lenders provide. Furthermore, government subsidies and public bonds greatly impact PPPs development financing.

The financial structure of the PPP schemes is the financial capital required for the project's progress, which is generally repaid from the revenue of the given project. Therefore, the stream of income and the project's assets for the required project will have a critical influence on determining the debt capacity of the project, unlike the examinations of the financial credits and the total portfolio in corporate finance. For the PPP project, this can be challenging because during the construction period, the project may not obtain any revenue, and the revenue stream will only start in the operation period. Therefore, long-term financial tools will be needed to handle the costs in the initial phases of the project until the project enters the operation stage and begins to generate sufficient revenue.

The financing cost of the PPP development may be the utmost significant aspect of the project. There may be a robust relationship between the financing cost rate of the project, the financing efficiency, and the investment's return rate, which can play an essential part in the public party's decision (Tao & Ji, 2015). For example, in the UK, the increased risks linked to PPP projects may be related to the increased financial costs and the lack of equity funds and short-term debts (Demirag et al., 2015). Therefore, the public parties should focus on achieving more participation from the private parties in debt investment and equity sharing.

2.2.2.2 PPP Financial Tools for Capital Structures

Capital Structure attainments in the PPP projects can be seen in three different tools:
1) Permanent capital, which can be seen in equities, includes common stocks, retained earnings, and unappropriated profits. The equity holders are usually repaid after the repayments of the project's financial obligations.

2) Temporary capital, which can be seen in debt, includes the senior debt, which has the most priority in repayment obligations, and the subordinated debt, which has a less priority than the senior debt in repayment obligations.

3) Quasi-equity, which can be seen in the mezzanine financing that can have both debt and equity properties as it can lay between the two tools. This includes convertible bonds that can trade with shares and the preferred stocks that are paid at a fixed share to secure the equity.

The equity level, which can be seen in the tools used, the amount and source of every tool, and the contractual agreements, will define the capital structure for PPP projects. Furthermore, the combined costs of these tools will characterize and determine the total capital cost of such projects.

Every tool has its influence on the PPP projects’ financial capacity. For instance, the equity cost can be greater than the debt cost due to the higher ROE value compared to the debt rate of interest. Therefore, reducing the PPP project’s total capital costs may be achieved by reducing the level of equity. Yet, lowering equities may result in greater risks from the lenders' perspectives as they tend to work mostly with a minimal level of risks, or a risk premium may be associated with the debt.

### 2.2.2.3 Equity Level

Both public and private sectors may agree on an adequate equity level that satisfies each party of the involved parties (e.g., equity holders or shareholders, the public sector, and the lenders). Determining the level of equity is critical in defining the project’s capital structure. Nevertheless, it is a challenging task due to the different views and requirements of the involved parties. The ideal
sharing ratio can be enhanced when all the involved parties balance their interests respectfully to their contribution to the actual contract. Where the public parties seek to smoothly implement the project sustainably with preserving public funds as much as possible, private parties' interests must be met to guarantee the PPP projects' continuous progress.

For the shareholders, equity’s IRR may act as a critical influence in their equity level determination as making profits is their primary motivation; thus, they will be looking for financially viable equity shares with an IRR maximisation (Zhang, 2005). Therefore, if the project's IRR value is small, the shareholders may require a minimum equity level to relocate their available funds to more profitable projects and simultaneously minimize their associated risks with the given project. IRR is the most common indicator (Cuthbert & Cuthbert, 2012), while the average IRR can be seen as a better indicator (Cuthbert & Magni, 2016).

Furthermore, the debt service coverage ratio (DSCR) minimal value is specified by lenders to opt to minimize their involvement risks. The minimum DSCR level may not be met with a small equity investment. Therefore, lenders may pursue a high equity ratio to ensure that the minimum DSCR level is satisfied (Zhang, 2005).

Lastly, the public sector equity level should be selected according to the project's sensitivity and conditions and the private sector's interest requirements. For instance, if the PPP project has a high sensitivity to the social welfare growth, yet the project is not profitable from the private parties' perspective, the public parties may provide a high amount of equity to meet the obligatory funds for the project development. Therefore, having a tool to determine each party's optimal required equity level contribution is critical in achieving an adequate capital structure and enhancing the PPP agreement's success.
The public and private participants have different perspectives on the concession. The project's capital structure and revenue sharing may serve as a tool to protect the interests of the participants. The capital structure of the concession reflects how the concession is being financed through debt (lenders' interests), equity (private and public equities that reflect ownerships of the project), and some other financial tools.

Debt is utilized based on the project's potential generated revenue. Therefore, if the potential revenue of the project is high, the project may be eligible for a high amount of debt. However, lenders may face some losses in their investments if the project does not generate enough revenue, even if they were promised to have their investment back with interest. Therefore, lenders tend to use two mechanisms to protect their investment in the project: DSCR and interest rate. DSCR is utilized to determine the debt capacity of the project, which should be larger than 1.2, to ensure that the revenue is always higher than the debt capacity of the project (Finnerty, 2007). On the other hand, the interest rate includes a risk premium that can be evaluated according to the related risks with the project, debt rating, and the project's revenue stability.

On the other hand, if the potential generated revenue is insufficient to obtain the required debt, further steps should be taken to ensure the funds are met. These steps can be achieved by acquiring a shortage of funds from the involved parties in the forms of public and private's equity. However, equity holders may take more risks than the lenders as repayments will occur after repaying debt service. Therefore, private parties will be focusing on the rate of return or a minimum level of IRR. In other words, if the rate of return is not sufficient, the private parties may not invest in the project as it may not be attractive enough for their investments. As a result, public parties may have to provide more funds in the form of equity, or they may have to give away a substantial percentage of their profits to attract private parties.
2.2.2.4 Public Participation in Capital Structure

Many scholars emphasize on the importance of the government role in providing nonstop capital investments in the infrastructure sector to enhance its economic growth (Berawi et al., 2014; Anwar, 2006; Benito et al., 2008; Clark & Root, 1999; Bin & Quan, 2012; Bom & Ligthart, 2014; Carranza et al., 2014; Daido & Tabata, 2013; Duran-Fernandez & Santos, 2014; Esfahani & Ramírez, 2003; Glomm & Ravikumar, 1999; Gupta & Barman, 2010; Heijdra & Meijdam, 2002; Mejia-Dorantes & Lucas, 2014; Zawawi et al., 2014; Percoco, 2014; Shi & Huang, 2014). Providing the capital investment by the public party may act as a means to ensure their responsibilities to the public's welfare through providing sustainable infrastructures to reach the society's development needs and enhancing the public economy. However, there is a shortage of public spending on needed infrastructure projects (Agénor, 2010; Sambrani, 2014; Wojewnik-Filipkowska & Trojanowski, 2013). Therefore, public parties should increase their participation in the PPP projects’ capital structure by obtaining more equities in a manageable way that may not negatively impact their interests. The participation of public parties in the capital structure of the concession should be large enough to attract more private competitors and raise the project’s debt capacity simultaneously. Yet, it should be small enough to mitigate the likely risks associated with the given project and preserve sustainable social welfare.

2.2.2.5 Private Participation in Capital structure

Private parties’ participation in the capital structure of the PPP development may act as a means to guarantee their efficiency and commitments, hence, reducing the public's risks. For example, with the participation of private parties in the projects’ capital structure, they may not risk their investments by abandoning the project in an early stage when they obtain enough profit to avoid costly operations and maintenance. They may be more willing to complete the project as required.
Therefore, a minimum level of private parties' participation in the capital structure should be imposed. In contrast, a large level of private's equity in a profitable project may negatively impact the public's interests and social welfare. Therefore, determining sufficient equity values between public and private parties is complicated due to the multi variables components affecting the decision.

2.2.2.6 Optimizing Capital Structure

Many researchers have investigated the implementation and designing of an optimal capital structure for PPP projects (Chen and Chiu, 2010; Hall, 2008; Moszoro, 2010; Hoppe and Schmitz, 2010; Allonso-Conde et al., 2007; Reeves, 2005; Fischer et al., 2010; Rajan et al., 2010; Takashima et al., 2010; Chung et al., 2010; Carmona, 2010; Bittegnies & Ross, 2009; Dewatripont & Legros, 2005) and by investigating these studies, four steps should be achieved to implement the optimal capital structure successfully:

1) Assessing the requirements of the public's interests. In this step, the need for the project should be evaluated based on the potential public interest and socially sustainable development growth.

2) Assessing the project requirements. In this step, the project size and the needed funds to construct the project should be evaluated and compared to the public's financial and operational capacity. The evaluation of the economic indicators should accomplish this and determine whether the public parties can perform and deliver the required project without the involvement of private investments and the assessment of alternative procurement approaches.

3) Assessing the PPP procurement approaches and conditions to deliver the project. In this step, the basis and conditions of the PPP approach should be assessed and evaluated based on the project's requirements. Different PPP approaches should be compared to allocate the most suitable approach for the project. In addition to allocating the private parties' level of participation.
4) Optimizing the capital structure of participants. The capital structure’s optimal level for every participant should be determined according to their involvement in the scheme and the possible risks related to developing the PPP scheme.

In general, financial models create deterministic values for the appropriate level of equity for private parties (Bakatian et al., 2003; Dias and Ioannou, 1995). However, using these financial models to create such deterministic values may lack uncertainties associated with the project. Hence, deciding the adequate level of equity should not be based on these predetermined values as it may lead to unexpected losses and risks. Therefore, the determinations of the proper capital structure should be based on feasible options for the participants to choose the adequate values.

Much quantitative financial research has been studied to examine the appropriate capital structure values. For example, some researchers investigated adequate capital structures using the Capital Asset Price Method (CAPM) (Dias and Ioannou, 1995), the linear programming method (Bakatjan et al., 2003), and the Monte Carlo simulation method (Zhang, 2005(a)). Other researchers studied economic and financial feasibility (Chang and Chen, 2001; Ho and Liu, 2002; Tiong and Alum, 1997; Ranasinghe, 1996).

Considering the capital structure benefits, Sharma et al. specified the finest investment of equity when the private fund interests are maximized while guaranteeing public interests (Sharma et al., 2010). In addition, (Sheng et al., 2013) attempted to reach an adequate capital structure by maximizing the private party’s benefits. Furthermore, the participants’ benefits should be tangible to their investments in the project (Toms et al., 2011).

Risks, moreover, substantially influence the projects’ capital structure acquisition. For example, the participants have different perspectives when it comes to risks. The lenders focus on low-risk
projects while the shareholders emphasize the equal distributions of risks (Demirag et al., 2011). Furthermore, the capital structure was investigated in view of construction risks and economic risks from different participants (Zhang, 2005). In addition, the Monte-Carlo simulation was utilized to optimize the capital structure via investigating the participants' risks (Yun et al., 2009).

The connection between the capital structure and the debt capacity has been studied using the (CAPM), which considers the expected return based on the associated risks (Dias and Ioannou, 1995). The authors started by assessing NPV and the ROE, where the ROE plays the objective function of reaching an optimal level of equity. On the other hand, linear programming was utilized to study the optimal values of capital structure (Bakatjan et al., 2003). The authors assessed the NPV, IRR, and DSCR to acquire the capital structure optimal values. Monte-Carlo simulation technique was also utilized to obtain the capital structure optimal values considering the project’s financial viability, which may be seen in the self-financing ability of the PPP project (Zhang, 2005(a)). Furthermore, to compute the equity cost and debt cost, the weighted average cost of capital is usually utilized (Frank & Shen, 2016). This method commonly calculates the cost of equity as one variable using the (CAPM) (Lintner, 1965), whereas the cost of debt is the other variable in the calculations (Vecchi et al., 2013).

Various other research has studied the effects of the capital structure ratios among the involved parties. For instance, (Yun et al., 2009) attempted to balance the capital structure among the participated parties by building a capital structure optimization model. The model includes the calculations of IRR and DSCR for a better profitability liquidity understanding. Moreover, (Jasiukevičius and Vasiliauskaitė, 2012) proposed a practical capital structure optimization tool used as a financial viability evaluation tool for the public and private parties. (Zhang, 2005), established a quantitative technique to assess the economic viability and optimize the capital structure between the involved parties. The tool could enhance the involved parties' decision-making by providing them with a tool.
that can enable them to control the adequate range of equity investments. Also, (Soumaré and Lai, 2016) attempted to compare the direct government investment and the government loan guarantee intended for the projects’ success. They concluded that public loan guarantees have more effects on reducing project borrowing costs.

Sharma et al. developed a linear and probability program design for evaluating the debt-equity investment in PPP contracts (Sharma et al., 2010). The model should enhance the public sector’s decision-making by providing them with a tool that can enable them to regulate the adequate range of private equity investments. Furthermore, Jasiukevicius and Vasiliauskaite created a tool to assess the likelihood of optimizing public infrastructure investment (Jasiukevicius and Vasiliauskaite, 2018). The goal of this model is to ease the decision-making procedure regarding the implementation of PPP. (Lomoro et al., 2020), evaluated the effects of public support adoption on the PPP performance for put-or-pay contracts. The goal of the evaluation was to study the impact of the put-or-pay agreement in optimizing risk allocation.

The research mentioned above has been concentrating on optimizing the capital structures through deterministic financial indicators values. However, using these economic models to create such deterministic values may lack uncertainties associated with the project. Hence, deciding the adequate level of equity should not be based on these predetermined values as it may lead to unexpected loses and risks. Not to mention neglecting other concession components, where the optimization of the capital structure alone can negatively affect the concession components such as concession period and price due to the conflicting interests between the concession components. Focusing on capital structure optimization alone can be seen as an economic perspective, hence neglecting the social and environmental perspectives, which may reduce their optimal potential values. Therefore, the determinations of the adequate capital structure should be based on feasible
options for the participants to choose the sufficient values through a tool that considers different concession variables in the optimization process.

2.2.3 Public Subsidy

The main goal for private sectors undertaking PPP projects is to profit. However, most of the projects operated under the PPP agreements make low profits due to the considerable current and future risks associated with such projects' long lifespan. Governments or public sectors should provide adequate subsidies for such poor profitability projects to make the project economically feasible for private sectors (Song et al., 2018; Wang, Cui, & Liu, 2018). These subsidies are essential due to the promising benefits of such low profitability projects to society's sustainable development. In other words, from the private sector's perspective, the needed infrastructure projects for social development may not see the light if the projects have no potential return on investment. Therefore, financial supports from the public parties, such as subsidies and guarantees, are essential to attract private parties due to the PPP's long lifespan and the risks that may be associated with its uncertainties (Khmel & Zhao, 2015; Chen et al., 2012; Kokkaew & Wipulanusat, 2014; Shaoul et al., 2012).

The estimated revenue for the private sector might be more than the actual revenue due to PPP projects' current and future risks (Wang et al., 2019). If the estimated revenue was specified in the agreement, the public sector should compensate for the difference between the estimated and the actual revenue (Buyukyoran & Gundes, 2018; Liu, Gao, & Cheah, 2017). When these compensations are considered, private sectors may be more willing to participate in such risky contracts.
The public sector's subsidy participation can be seen in many ways, such as providing direct liquidity subsidies, loan guarantees, free allocations of land use, or giving up some already-owned equity by the public party.

The key goal of public parties is maximizing social welfare and adequately delivering the required infrastructures. It can be clear that public subsidies have an inverse relationship with the concession period and the concession price. The more value of subsidies issued by the public parties to the concession, the less period and price the concession will require to pay back its investments. Therefore, government subsidies may act as an effective tool to decrease the concession period and price. Alternatively, public parties can reduce their initial financial contribution to the project by elongating the concession period or by increasing the concession price.

The ideal sharing ratio can be enhanced when all the involved parties balance their interests respectfully to their contribution to the actual contract. Where the public parties seek to smoothly implement the project sustainably with preserving public funds as much as possible, private parties' interests must be met to ensure the continuous progress of PPP schemes.

It may be worth mentioning that public parties, on the other hand, may be eligible to acquire any extra revenue the private parties may obtain. The factors for defining the excess revenue's ideal sharing ratio were evaluated by Wang and Liu (Wang & Liu, 2015).

### 2.2.3.1 Public Parties’ Guarantees

The public subsidies can be seen in the form of different guarantees such as; a concession guarantee (Galera & Solino, 2010), a minimum demand guarantee, which guarantees a minimum level of user flow to the project to ensure a sufficient revenue stream (Song et al., 2018; Wang et al., 2019), price adjustment, which provides the private parties gain adequate profitability (Qiu & Wang, 2011;
Carvalho & Nechio, 2011; Xu et al., 2012), tax relief which reduces the overall cost burden by exempting investors from paying specific amounts of taxes (Chen et al., 2012), a restrictive competition which tackles the potential monopolies contracts may have (Martins et al., 2011; Liu, Yu, & Cheah, 2014; Sarmento & Renneboog, 2016), a land lease which can be seen in the allocation of lands to be used for projects execution (Chen et al., 2012), and the potential change in currency or interest rates (Du & Li, 2008; Hanaoka & Palapus, 2012).

In addition to the revenue guarantee and loan repayment guarantee. Revenue guarantees where could be characterized by trigger variables (the threshold of the guarantee) and the compensation approach (which can be seen in payments, subsidies, or concession period extensions) (Asao et al., 2013). The threshold considers the annual income, the total income, and the IRR. The public party's reimbursement occurs when a trigger variable surpasses the pre-agreed-upon minimum edge. Adequate compensation is then selected by the public sectors depending on the given situation. Moreover, a loan repayment guarantee may be used to attract investors who have less financing costs than private capital (Kurniawan et al., 2015; Zhang, 2014).

It can be clear that the public parties' guarantees are used to attract more private parties and enhance their competitiveness. However, preserving public funds and budget is as critical as attracting the participation of private sectors. Therefore, a tool that can balance all the involved parties' interests is vital in the scope of PPPs.

### 2.2.3.2 Optimizing Public Subsidies

Several investigations have been studied in the literature to investigate and optimize the level of public subsidies to PPP projects. Soumaré and Lai attempted to compare the direct government investment and the government loan guarantee for the projects’ success (Soumaré & Lai, 2016). They
concluded that government loan guarantees have more effects on reducing project borrowing costs. Chen and Subprasom propose that with the existence of price rules, the public subsidies may act as adequate means to reach the financial feasibility for the private parties (Chen & Subprasom, 2007). Furthermore, Feng et al. examine the optimum public subsidies design in the occurrence of a non-contractible performance by the private parties by implementing a linear per-period subsidy arrangement (Feng et al., 2016). Moreover, Tan & Yang integrate public subsidies into a flexible PPP agreement design problem by the presumption that public subsidies can compensate the private parties (Tan & Yang, 2012).

However, the public subsidies optimizations studies for PPP schemes, both in the position of the main objective or a sub-objective, are very limited in the literature. Therefore, this study may be useful for investigating the impact of such public subsidies on the PPP procurement approach implementations. And to determine the optimal subsidy value when related to other concession components.

Public subsidies can be seen as a risk-sharing mechanism to balance both parties' interests (Wibowo et al., 2012). However, determining the adequate amount of Subsidy is the challenging part. The Subsidy should be large enough to cover the potential losses that private sectors may face and to act as a leverage tool for the public parties to increase such participation and competition of the private parties. Furthermore, at the same time, it should be small enough to preserve the public budget and social welfare. Determining the right amount of Subsidy will affect other related factors in the PPP contract. For instance, reaching an optimal amount of government subsidy will reduce the optimal value of other factors. Therefore, a tool that considers several PPP contract factors is needed due to the conflicting interests between factors. These factors' economic, social, and environmental dimensions should also be considered.
2.2.4 Sustainability Performance

Sustainability development can be defined as meeting today's goals without negatively affecting the resources for the next generations to meet their goals. Moreover, sustainability development focuses on three critical pillars: economy, social, and environment. Interestingly, Although PPP projects are usually mega projects in their nature and are constructed over a very long lifespan, the concept of sustainable development is barely touched in such projects (Hueskes et al., 2017). Thus, this may lead the agreements to only acquire short-term profits instead of long-term profits applicable to all sustainability dimensions.

Since the “Our Common Future” report in 1987 (World Commission on Environment and Development, 1987), followed by the Rio de Janeiro Summit in 1992, the idea of adopting sustainability development has increased among many industries and the construction industry. However, implementing the sustainable development aspects into the construction industry is a difficult task due to the various aspects and complexities of the construction projects.

Infrastructure developments contribute to social welfare, and national competitiveness substantially affects social and economic sustainability development goals (Algarni et al., 2007; Ke, 2014; Robert et al., 2014).

Usually, the most focused dimension when dealing with PPP projects is the economic dimension, where all shareholders emphasize the project's financial sustainability (Bennett, 1998). Because for them to ensure that the initial capital investment is paid back with the expected profits. From the sustainable economic perspective, PPP can be seen as a way of delivering infrastructures to achieve the sustainable development growth needed when governments do not have enough funds. Hence, this may be very helpful, especially for developing countries where they can meet their sustainable
growth development by utilizing private investments and capital. PPP can also be seen as new business prospects for the private parties to invest and profit. Hence, private sectors may have the ability to improve their sustainable economic development by undertaking PPP projects.

While other sustainability dimensions are somehow neglected in the PPP contracts, for example, when signing PPP agreements, the environmental dimension can be considered in advancing the protection of the urban environment (Kościelniak and Górka, 2016). Also, the private sector should consider long-term sustainability impacts to enhance the urban environment (Koppenjan and Enserink, 2009).

Furthermore, the social dimension is as critical as the other two dimensions, where every participating sector in the PPP agreements should consider social sustainability when constructing PPP projects (Bennett, 1998). From the social point of view, public entities should seek to optimize their interests in investments by assessing the impacts of implementing PPP projects, thus, providing sustainable services for a society where the quality and price of the services are socially feasible (Silvestre, 2012; Diana, 1995; Sambrani, 2014; Mamatzakis, 2007; Maskin & Tirole, 2008; Kellermann, 2007). The application of the PPP procurement approach may provide sustainable services while reserving public budgets (Abednego & Ogunlana, 2006). The improvement of social welfare should be the driving force for the public sectors to undertake such projects. Therefore, protecting the social, economic, and environmental sustainability developments when assigning PPP contracts should not be tolerated.

2.2.4.1 Concession Period and Price from a Sustainable Perspective

The concession period and price play a significant part in the Sustainability Development of PPP projects. Hence, the determination of the fair values of the concession period and price need to be
based on sustainable mutual benefits between the concession participants. The concession participants play different parts in the development of the concession and have different perspectives and goals. Therefore, the concession design needs to be constructed to balance the sustainable interests of the involved parties to ensure a smooth and sustainable development of the project. In other words, the PPP concession should be attractive for private parties and investors to attract more participants through an adequate and sustainable return rate. The main aim of defining the concession period and price is to ensure a suitable and sustainable revenue for private sectors to recover their capital investment (Shen et al., 2002). Private sectors may require long concession periods to reap enough revenue by collecting user payments in most cases. In contrast, the public sector may require shorter durations to protect the public's interests.

Moreover, the private parties may have a mechanism in the concession agreement which allows them to increase the concession price if the generated revenue is smaller than the estimated revenue (Ngee, 1997). However, this will negatively affect the public interests as their interest is to keep the concession price at a lower level to meet social welfare and protect sustainable social development.

On the other hand, concession prices should be selected carefully by considering the public's sustainable interest. The concession price is usually determined based on the society's average per capita income to ensure meeting the public needs while providing an adequate users-flow to increase the cash flow for generating the project's revenue. The concession period and price have an inverse relationship. The higher the concession price is, the shorter the project's concession period may require repaying its development investment. On the contrary, if the concession price is set low by the public agencies, the project may require a more extended concession period to generate sufficient revenue. Or additional public support in the forms of subsidies or guarantees may be needed to cover the insufficient revenue stream.
Choosing the ideal and sustainable period and the price is complicated, and it depends on several factors that may differ from one project to another. The concession price should be adequately large to cover the investment of the private parties in short concession periods. At the same time, it should be small enough to preserve the public's welfare and ensure adequate user flow. In addition, determining the right value of the concession period and price will affect other related factors and concessionary items in the PPP contract. For instance, reaching an optimal concession period will reduce the optimal values of the other concession factors. Therefore, a tool that takes several PPP concession sustainability factors into account is needed due to the conflicting interests between concession factors and the conflicting interests between the participants.

2.2.4.2 Capital Structure from a Sustainable Perspective

The determination of Capital Structure has a substantial impact on the PPP projects' Sustainability Development. In general, PPP project funds can be seen in three different forms: public funds, debt, and equity. Furthermore, determining the level of equity is critical for defining the project's sustainable capital structure. Nevertheless, it is a challenging task due to the different views and requirements of the involved parties. The sustainable sharing ratio can be enhanced when all the involved parties balance their sustainability interests respectfully to their contribution to the contract. Where the public parties seek to smoothly implement the project sustainably with preserving public funds as much as possible, private parties’ interests must be met to ensure the PPP projects’ continuous progress.

The perspectives of sustainability from the public and private participants are different in the concession. The project's capital structure and revenue sharing may serve as a tool to protect the sustainable interests of the participants. The capital structure of the concession reflects how the
concession is being financed through debt (lenders' interests), equity (private and public equities that reflect ownerships of the project), and some other financial tools.

Providing the capital investment by the public party may act as a means to ensure their responsibilities to the public's welfare through providing sustainable infrastructures to meet the society's sustainable development needs and enhancing the public economy. However, there is a shortage of public spending on needed infrastructure projects (Agénor, 2010; Sambrani, 2014; Wojewnik-Filipkowska & Trojanowski, 2013). Therefore, public parties should increase their capital structure participation in the PPP projects by obtaining more equities in a manageable and sustainable way that may not negatively impact their sustainable interests. The involvement of public parties in the capital structure of the concession should be large enough to attract more private competitors and raise the project's debt capacity simultaneously. Yet, it should be small enough to mitigate the likely risks related to the project and preserve sustainable social welfare.

On the other hand, private parties' participation in the project's capital structure may be a way to guarantee their efficiency and commitments, hence reducing the public's risks. Therefore, a minimum level of private parties' participation in the capital structure should be imposed. In contrast, a large level of private's equity in a profitable project may negatively impact the public's interests and social welfare. Therefore, determining sufficient equity values between public and private parties is complicated due to the multi variables components affecting the decision.

Focusing on capital structure optimization alone can be seen as an economic perspective, hence neglecting the social and environmental perspectives, which may reduce their optimal potential values. Therefore, the determinations of the adequate capital structure should be based on feasible options for the participants to choose the proper values through a tool that considers different concession variables in the optimization process.
2.2.4.3 Public Subsidy from a Sustainable Perspective

Public Subsidy plays an essential part in the Sustainability Development of PPP projects. These subsidies are crucial due to the promising benefits of such low profitability projects to society's sustainable development. In other words, from the private sector’s perspective, the needed infrastructure projects for social development may not see the light if the projects have no potential return on investment. Therefore, financial supports from the public parties, such as subsidies and guarantees, are essential to attract private parties due to the PPP’s long lifespan and the risks that may be associated with its uncertainties (Shaoul et al., 2012; Kokkaew & Wipulanusat, 2014; Chen et al., 2012; Khmel & Zhao, 2015).

The estimated revenue for the private sector might be more than the actual revenue due to PPP projects' current and future risks (Wang et al., 2019). If the estimated revenue was specified in the agreement, the public sector should compensate for the difference between the estimated and the actual revenue (Buyukyoran & Gundes, 2018; Liu, Gao, & Cheah, 2017). When these compensations are considered, private sectors may be more willing to participate in such risky contracts.

The main goal of public parties is to maximize social welfare and deliver the required infrastructures adequately. It can be clear that public subsidies have an inverse relationship with the concession period and the concession price. The more value of subsidies issued by the public parties to the concession, the less period and price the concession will require to pay back its investments. Therefore, government subsidies may be an effective tool to decrease the concession period and price. Alternatively, public parties can reduce their initial financial contribution to the project by elongating the concession period or by increasing the concession price.

The ideal sharing ratio can be enhanced when all the involved parties balance their interests respectfully to their contribution to the actual contract. Where the public parties seek to smoothly
implement the project sustainably with preserving public funds as much as possible, private parties’ interests must be met to ensure the PPP projects’ continuous progress.

On the other hand, public parties may be eligible to acquire any extra revenue the private parties may obtain. The factors for defining the excess revenue’s ideal sharing ratio were evaluated by Wang and Liu (Wang & Liu, 2015).

Public subsidies can be seen as a risk-sharing mechanism to balance both parties’ interests (Wibowo et al., 2012). However, determining the adequate amount of Subsidy is the challenging part. The Subsidy should be large enough to cover the potential losses that private sectors may face and act as a leverage tool for the public party to increase the participation and competition of the private parties. Furthermore, at the same time, it should be small enough to preserve the public budget and social welfare. Determining the right amount of Subsidy will affect other related factors in the PPP contract. For instance, reaching an optimal amount of government subsidy will reduce the optimal value of other factors. Therefore, a tool that considers several PPP contract factors is needed due to the conflicting interests between factors. These factors’ economic, social, and environmental dimensions should also be considered.

Assessing and optimizing the public interests in the PPP procurement approach may still be seen as a difficult quantitative task scientifically due to the many factors involved in the process of decision making. There may be an absence of complex models in the literature that can thoroughly evaluate and optimize the public’s interests. Optimizing the public’s interests in the PPP projects has not been fully analyzed, and there still be a need for an adequate quantitative model to assess such interests.

The main promising goal is to reach the optimal outcomes for all aspects of the PPP projects, considering the economic and social aspects which may be affected by the agreement. Therefore, a
tool that considers several PPP contract factors from all economic, social, and environmental perspectives is needed due to the conflicting interests between factors.

2.2.4.4 Optimizing the Sustainability Performance

Many studies investigated the PPP projects’ sustainability performance. For instance, Shen et al. examined the PPP projects’ sustainability performance according to the effects of the contribution arrangements among the participated parties (Shen et al., 2016). They introduced a sustainability tool to support the PPP projects’ sustainability performance valuation. The study aimed to provide an optimal investment distribution among the involved parties, which can benefit the PPP projects’ sustainability performance.

The performance was utilized to examine the PPP project feasibility by striking the tradeoffs among the sustainability dimensions (Plessis, 2001; Shen et al., 2002; Ogwu et al., 2006). Accordingly, several sustainability performance assessment models were created for this purpose.

A model called the Sustainability appraisal in Infrastructure projects was proposed by Ogwu et al. to examine the sustainability performance of infrastructure projects based on several factors (Ogwu et al., 2006). Another model for better sustainability performance was proposed to determine the number of practical choices to smooth decision-making for the PPP procurement approach (Dasgupta & Tam, 2005). An additional study was conducted by Shen et al. for a better sustainability performance, which concluded that the concession period should be selected based on incorporating the contributions and goals of every involved participant in the agreement (Shen et al., 2002). Moreover, the sustainable benefits to the PPP project participants were also studied by Shen and Wu based on the risk-based concession period (Shen & Wu, 2005).
It can be clear that the previous studies investigated the assessments of the sustainability performance of PPP projects. However, these studies may lack the mechanism of improving sustainability performance rather than merely assessing it. PPP projects' sustainability indicators were also investigated qualitatively in the literature (Ogwu et al., 2006). Yet, there is a clear need for quantitative methods to address the sustainability performance of PPP projects. These quantitative methods need to take all the PPP participants' contributions and expected outcomes into account to examine better and improve the sustainability performance outcomes. Because the participants' contributions to the PPP projects, which can be seen in investment distributions, risk allocations, public subsidies, etc., have a substantial impact on the concession aspects and the economic and social sustainability performance of such projects. Every participant in the PPP agreement has different goals and expectations. Hence, taking these expectations into account and applying them to the long-term agreement may result in better sustainability performance for the PPP projects.

2.3 Selected Literature Review

A selected literature review of the previous concession items is illustrated in tables 2 and 3.
Table 2. Selected Studies based on the Objectives and Methods.

<table>
<thead>
<tr>
<th>Selected Reference</th>
<th>Objectives</th>
<th>Methods</th>
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<tbody>
<tr>
<td>Tan et al., 2010</td>
<td>Analyzing the Private’s Party Behavior</td>
<td>bi-objective programming model</td>
</tr>
<tr>
<td>Niu &amp; Zhang, 2013</td>
<td>Examining demand uncertainties’ impact on the concession period, price, and capacity</td>
<td>bi-objective programming model</td>
</tr>
<tr>
<td>Tan &amp; Yang, 2012</td>
<td>Examining the flexibility of the BOT agreement due to demand uncertainties</td>
<td>bi-objective programming model</td>
</tr>
<tr>
<td>Wu et al., 2011; Shen et al., 2002</td>
<td>Modeling the concession period</td>
<td>NPV Calculations</td>
</tr>
<tr>
<td>Shen et al., 2005; Bao et al., 2015; Yang et al., 2007; Peng et al., 2014; Shen et al., 2007; Hanaoka &amp; Palapus, 2012 Carbonara et al., 2014; Zhang, 2009</td>
<td>Choosing the adequate concession interval in which to balance the involved parties’ interests by describing the accumulated NPV curve</td>
<td>Game Theory, Simulation Modeling</td>
</tr>
<tr>
<td>Shen et al., 2002</td>
<td>Choosing the adequate concession interval in which to balance the involved parties’ interests by describing the accumulated NPV curve</td>
<td>Quantitative model</td>
</tr>
<tr>
<td>Peng et al., 2014</td>
<td>Optimizing the concession period and the public Subsidy</td>
<td>Option game tool</td>
</tr>
<tr>
<td>Yang et al., 2007</td>
<td>Determining the best plans for public parties in the concession period in addition to the private parties’ corresponding investment</td>
<td>Stackelberg strategic game tool</td>
</tr>
<tr>
<td>Zhang &amp; Abourizk, 2006; Shen &amp; Wu, 2005</td>
<td>Determining the adequate concession period based on different financial variables, including the NPV,</td>
<td>Monte Carlo simulation</td>
</tr>
<tr>
<td>Selected Reference</td>
<td>Objectives</td>
<td>Methods</td>
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<tr>
<td></td>
<td>concession price, discount rate, capital structure, revenue, and construction period</td>
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<tr>
<td>Ng et al., 2007(a)</td>
<td>Determining the less risky concession period for private parties by obtaining several potential options for the IRR</td>
<td>Simulation Modeling</td>
</tr>
<tr>
<td>Arata et al., 2016</td>
<td>Modeling concession period and price</td>
<td>Road concession model</td>
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<tr>
<td>Asiedu &amp; Ameyaw, 2020</td>
<td>Modeling concession period and price</td>
<td>Empirical testing model</td>
</tr>
<tr>
<td>Alghamdi et al., 2022</td>
<td>Concession period, price, capital structure, government subsidy, and Sustainability Performance</td>
<td>Multi-objective Optimization</td>
</tr>
<tr>
<td>Lv et al., 2020</td>
<td>Subsidies, loss factors, and public sector position</td>
<td>Monte Carlo Simulation</td>
</tr>
<tr>
<td>Gross &amp; Garvin, 2009</td>
<td>Concession period and toll-rate structuring</td>
<td>Dual-variable Approach</td>
</tr>
<tr>
<td>Hadi &amp; Erzaij, 2019</td>
<td>Internal return rate, payback tariff, and concession period</td>
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<tr>
<td>Kokkaew &amp; Tongthong, 2021</td>
<td>Concession period and revenue sharing rate</td>
<td>Monte Carlo Simulation</td>
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<td>Liu et al., 2018</td>
<td>Concession period</td>
<td>Empirical model</td>
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<tr>
<td>Yuan et al., 2021</td>
<td>Concession price</td>
<td>Principal-agent theory</td>
</tr>
<tr>
<td>Ng et al., 2007(b)</td>
<td>An extension of the previous study which can help in trading off three different concession variables</td>
<td>Extended Simulation Modeling</td>
</tr>
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<td>Ngee et al., 1997</td>
<td>Designing of the concession period</td>
<td>Multiple linear regression</td>
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<tr>
<td><strong>Selected Reference</strong></td>
<td><strong>Objectives</strong></td>
<td><strong>Methods</strong></td>
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<tr>
<td>Yu &amp; Lam, 2013</td>
<td>Designing the concession period</td>
<td>Decision support system method using Monte Carlo simulations</td>
</tr>
<tr>
<td>Wang et al., 2018</td>
<td>Designing an optimized BOT contract</td>
<td>Stylized Optimization tool</td>
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<tr>
<td>Feng et al., 2019</td>
<td>Optimizing the concession period under some assumptions introducing the influence of public equity as well as the time value for money</td>
<td>Quantitative model</td>
</tr>
<tr>
<td>Scandizzo and Ventura, 2010</td>
<td>Modeling the concession contracts between the involved parties</td>
<td>Real options theory</td>
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<td>Dias and Ioannou, 1995</td>
<td>Examining the appropriate capital structure values, which take into account the expected return based on the associated risks</td>
<td>Capital Asset Price Method (CAPM)</td>
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<tr>
<td>Bakatjan et al., 2003</td>
<td>Examining the appropriate capital structure values via assessing the NPV, IRR, and DSCR to acquire the capital structure optimal values</td>
<td>Linear programming</td>
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<tr>
<td>Zhang, 2005(α)</td>
<td>Examining the appropriate capital structure values considering the projects' financial viability</td>
<td>Monte Carlo simulation</td>
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<tr>
<td>Yun et al., 2009</td>
<td>Optimizing the capital structure via investigating the participants' risks</td>
<td>Monte Carlo simulation</td>
</tr>
<tr>
<td>Frank &amp; Shen, 2016</td>
<td>Computing the equity cost and debt cost</td>
<td>A weighted average cost of capital cost</td>
</tr>
<tr>
<td>Jasiukevičius &amp; Vasiliauskaitė, 2012</td>
<td>Evaluating the financial viability for both public and private parties</td>
<td>A practical capital structure optimization tool</td>
</tr>
<tr>
<td>Selected Reference</td>
<td>Objectives</td>
<td>Methods</td>
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<td>Sharma et al., 2010</td>
<td>Evaluating the debt-equity investment in PPP contracts</td>
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<td>Jasiukevicius &amp; Vasiliauskaite, 2018</td>
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<td>Feng et al., 2016</td>
<td>Examining the optimum public subsidies design in the occurrence of a non-contractible performance by the private parties</td>
<td>Linear per-period subsidy arrangement</td>
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<td>Tan &amp; Yang, 2012</td>
<td>Evaluating the role of public subsidies in compensating the private parties</td>
<td>Integrating public subsidies into a flexible PPP agreement design</td>
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<td>Shen et al., 2016</td>
<td>Examining the PPP projects’ sustainability performance according to the effects of the contribution arrangements among the participated parties</td>
<td>Sustainability Optimization tool</td>
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<td>Ogwu et al., 2006</td>
<td>Examining the sustainability performance of infrastructure projects</td>
<td>Sustainability appraisal model</td>
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<td>Dasgupta &amp; Tam, 2005</td>
<td>Determining the number of practical choices to smooth the process of decision making for the PPP procurement approach</td>
<td>Sustainability framework</td>
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Table 3. Optimization Studies based on the Objective Concession Items.

<table>
<thead>
<tr>
<th>Selected Reference</th>
<th>Method</th>
<th>Concession</th>
<th>Concession Price</th>
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<th>Performance</th>
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<td>Public Subsidy</td>
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<td>Performance</td>
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<tr>
<td>lv et al., 2020</td>
<td>Monte Carlo Simulation</td>
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<tr>
<td>gross &amp; garvin, 2009</td>
<td>Dual-variable Approach</td>
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<td>hadi &amp; erzaij, 2019</td>
<td>Stepwise Approach</td>
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<td>jin et al., 2019</td>
<td>Game theory</td>
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<td>kokkaew &amp; tongthong, 2021</td>
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<tr>
<td>liu et al., 2018</td>
<td>Empirical model</td>
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<tr>
<td>yuan et al., 2021</td>
<td>Principal-agent theory</td>
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<tr>
<td>yu &amp; lam, 2013</td>
<td>Monte Carlo simulations</td>
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<tr>
<td>wang et al., 2018</td>
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<td>feng et al., 2019</td>
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<td>scandizzo and ventura, 2010</td>
<td>Real options theory</td>
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<td>dias and ioannou, 1995</td>
<td>Capital Asset Price</td>
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<td>Method (CAPM)</td>
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<tr>
<td>bakatjan et al., 2003</td>
<td>Linear programming</td>
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<td>Method</td>
<td>Concession Price</td>
<td>Capital Structure</td>
<td>Public Subsidy</td>
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<td>Performance</td>
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<td>Zhang, 2005(a)</td>
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<tr>
<td>Frank &amp; Shen, 2016</td>
<td>A weighted average cost of capital</td>
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<td>Jasiukevičius and Vasiliauskaitė, 2012</td>
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<td>Sharma et al., 2010</td>
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<tr>
<td>Feng et al., 2016</td>
<td>Linear subsidy arrangement</td>
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<td>Tan &amp; Yang, 2012</td>
<td>Integrating public subsidies into a PPP agreement design</td>
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<td>Shen et al., 2016</td>
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<td>Ogwu et al., 2006</td>
<td>Sustainability appraisal model</td>
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<tr>
<td><strong>Selected Reference</strong></td>
<td><strong>Method</strong></td>
<td><strong>Objective Concession Items</strong></td>
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<td>Dasgupta &amp; Tam, 2005</td>
<td>Sustainability framework</td>
<td>Sustainable ✓</td>
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<tr>
<td>Alghamdi et al., 2022</td>
<td>Multi-objective Optimization Model</td>
<td>Sustainable ✓ Performance ✓ Public Subsidy ✓ Capital Structure ✓ Concession Price ✓ Concession ✓</td>
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CHAPTER 3: THE SOCIO-ECONOMIC SYSTEM DYNAMIC APPROACH

Public-Private Partnerships (PPP) have many critical socioeconomic 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 socioeconomic 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 chapter aims to build a novel socioeconomic 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 resulted in 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 reverse 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 chapter gives a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic variables and is potentially valuable in facilitating and enhancing the decision-making process for PPP projects.

1 This chapter is currently under a final review in a peer-reviewed journal.
3.1 Introduction

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 (Kazancoglu et al., 2021). Public-Private Partnerships (PPP) are long-term agreements in developing infrastructure constructed between public and private parties (European Commission, 2003). The private sector's role in PPPs includes designing, developing, managing, financing, and operating government projects. Countries can develop their infrastructures through PPPs, thus fostering economic growth and development (Osei-Kyei and Chan, 2016, Sharma, 2012).

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 a myriad of developmental challenges, including dynamic complexities, nonlinearities, and time delays (Asiedu and Ameyaw, 2020; Qazi, 2020; Dikamen et al., 2021; Daniel & Daniel, 2019; Nyarirangwe et al., 2019). Over the recent years, the critical concession variables (price and period) have presented significant complexities for decisions and policymakers (Xu et al., 2012, Jayasuriya et al., 2019). Some of the critical concession variables are time and cost (Liang & Jia, 2018), equity and debt (Du, Wu, & Zhao, 2018), and cash inflows and outflows (Ma, Du, & Wang, 2018). 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 (Ogunlana et al., 2003). Techniques for system dynamics (SD) have provided a more profound understanding of the holistic perspective of PPPs. Shire et al. (2018) 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 (Georgiadis & Besiou, 2008). 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 (Radzicki, 2020). Therefore, the current study hypothesizes that assessing the dynamic relationship between the concession factors and components using a novel SD model can enhance the development of PPP agreements. The first significance of this study is that it combines more than one SEV in assessing the effectiveness of PPP using the SD model. Though this model has been under serious scrutiny in the past, it is now being embraced by
economists worldwide for its ability to include new approaches in understanding how PPP can improve SEV. 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 socioeconomic variables. Third, this study is a timely reminder that policymakers have vital roles to play in ensuring that policies encouraging how PPP improves socioeconomic variables are set up and may give insights on how to boost local production.

3.2 Related Work

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. (2018) 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 a period of 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, Ullah et al. (2018) study does not lay down the critical success factors that determine this period. Therefore, this provides a significant limitation for the study. Similar to the reviewed study, the paper in focus seeks to leverage the systems dynamics technique in modelling the relationships between key concession variables. Jin et al. (2019) 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 Patrokolos (2019) proposed an SD model to study PPP development's sustainable financial 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 (Pagoni & Patrokolos, 2019). 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 sustainability performance of the PPP projects. Zhang et al. (2020) 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. (2012) 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 were bound to arise during price determination.
Just like the studies reviewed above, the paper in focus adopts the systems dynamic technique in its modelling approach.

Du et al. (2018) performed a study on the PPP’s capital structure's critical factors. Scientific capital structure is usually crucial to ensuring that PPPs have sufficient funds to run. Nonetheless, they indicated that having an inappropriate capital structure would lead to many PPP projects’ failure. Seven critical factors impacted the PPP projects’ capital structure as identified by Du et al. (2018). The top critical factors were a benefit, cost, government support, external situation, and the private sector’s ability (Feng et al., 2017). 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. (2020) developed a tool to determine the appropriate subsidies for railway projects. Through a system dynamics approach, Lv et al. (2020) 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. (2020) 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. (2020) 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 between the PPPs' involved parties were also investigated in the literature. Yuan et al. (2018) 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. (2018) 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 sector would use the public funds for projects that cannot be financed through user-pay. Feng et al. (2018) 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 agreement. 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. (2019) argued that sustainability is the long-term ability to sustain the PPP operations to benefit all stakeholders. A summary table is given in Table 4.
Table 4. Concession variables and models used by previous studies.

<table>
<thead>
<tr>
<th>S/N</th>
<th>Concession variables</th>
<th>Model used</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Demand Forecasting</td>
<td>System Dynamic</td>
<td>Alasad et al. (2013)</td>
</tr>
<tr>
<td>2</td>
<td>Concession price and period</td>
<td>Road concession model</td>
<td>Arata et al. (2016)</td>
</tr>
<tr>
<td>3</td>
<td>Concession price and period</td>
<td>System dynamics causal loop (SDCL)-empirical testing model</td>
<td>Asiedu and Ameyaw (2020)</td>
</tr>
<tr>
<td>4</td>
<td>Concession period</td>
<td>The ‘win-win’ model and Monte Carlo simulation</td>
<td>Carbonara et al. (2014)</td>
</tr>
<tr>
<td>5</td>
<td>59 variables, including investment size, concession period, and project income</td>
<td>System Dynamic</td>
<td>Ullah et al. (2018)</td>
</tr>
<tr>
<td>7</td>
<td>Benefit, cost, government support, external situation, and private sector’s ability</td>
<td>System Dynamic</td>
<td>Du et al. (2018)</td>
</tr>
<tr>
<td>8</td>
<td>Concession period, price, capital structure, government subsidy, and Sustainability Performance</td>
<td>The multi-objective optimization model</td>
<td>Alghamdi et al. (2022)</td>
</tr>
<tr>
<td>9</td>
<td>Subsidies, loss factor, and public sector position</td>
<td>Monte Carlo Simulation</td>
<td>Lv et al. (2020)</td>
</tr>
<tr>
<td>10</td>
<td>Concession period</td>
<td>Concession period-mathematical model (partly assumptions-based)</td>
<td>Feng et al. (2019)</td>
</tr>
<tr>
<td>11</td>
<td>Concession period and toll-rate structuring</td>
<td>Dual-variable approach</td>
<td>Gross and Garvin (2009)</td>
</tr>
<tr>
<td>12</td>
<td>Internal return rate, payback tariff, and concession period</td>
<td>Stepwise approach (no model followed)</td>
<td>Hadi and Erzaij (2019)</td>
</tr>
<tr>
<td>S/N</td>
<td>Concession variables</td>
<td>Model used</td>
<td>Reference</td>
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<tr>
<td>13</td>
<td>Concession period</td>
<td>Game Theory- evaluating model</td>
<td>Jin et al. (2019)</td>
</tr>
<tr>
<td>14</td>
<td>Concession period and revenue</td>
<td>Monte Carlo and risk premium</td>
<td>Kokkaew and Tongthong (2021)</td>
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<tr>
<td></td>
<td>sharing rate</td>
<td>approach</td>
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</tr>
<tr>
<td>15</td>
<td>Concession period</td>
<td>Empirical model</td>
<td>Liu et al. (2018)</td>
</tr>
<tr>
<td>16</td>
<td>Various critical performance factors</td>
<td>Quantitative approach</td>
<td>Opawole et al. (2018)</td>
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<tr>
<td></td>
<td>– legal, technological, procurement, and economic.</td>
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<tr>
<td>17</td>
<td>Concession price</td>
<td>System Dynamic</td>
<td>Xu et al. (2012)</td>
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<tr>
<td>18</td>
<td>Concession price</td>
<td>Principal-agent theory</td>
<td>Yuan et al. (2021)</td>
</tr>
<tr>
<td>19</td>
<td>Subsidy and Concession Price</td>
<td>System Dynamic</td>
<td>Yuan et al. (2018)</td>
</tr>
<tr>
<td>20</td>
<td>Concession period</td>
<td>System Dynamic</td>
<td>Zhang et al. (2018)</td>
</tr>
</tbody>
</table>

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, is pertinent to understanding how PPP can improve and sustain socioeconomic 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 (in the form of equity) into account to better examine the system from a socioeconomic sustainability perspective. Previous studies have indicated that these components are long-term indicators of how successful the PPP will be (Garvin and Bosso, 2008, Xu et al., 2012, Sinsterra-Rodriguez, 2021); hence they are considered in the present study.
3.3 Model Development

The model development process follows a systematic approach, including qualitative and quantitative steps (Figure 2). The qualitative process starts from the 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 feedbacks of the system. 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 in interest, conceptualizes the modelling system, formulates the model, and validates it.

![Figure 2. The model development process.](image)

3.3.1 Problem identification

PPP has many critical socioeconomic 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. The selected concession variables feature in many studies as exogeneous variables and can be assumed not to be directly influenced by other concession variables. Assessing the dynamic and interdependent relationships between the socioeconomic concession components can enhance the PPP concessions development.

System Dynamics (SD) techniques have provided a deep system understanding from a holistic perspective in several complex structures (Turner et al., 2016; Shire et al., 2018; Azar, 2012). The paper in focus aims to build a novel socioeconomic 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) 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.

### 3.3.2 Identification of parameters

In this section, model variables are defined as endogenous variables determined within the model's scope and exogenous variables determined outside the model's scope (Table 2). Endogenous variables are the elements that are interactive within the system, influencing all the other variables. On the other hand, Exogenous variables are factors that are not enclosed by the system boundary but influence the system (constants not influenced by variables enclosed within the system). Tables 5 and 6 show a summary of these parameters including their units of measurement.
### Table 5. Model Variables Identification.

<table>
<thead>
<tr>
<th>Endogenous Variables (units)</th>
<th>Exogenous Variables (units)</th>
</tr>
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<tbody>
<tr>
<td>Concession Period (Years)</td>
<td>Traffic volume growth Rate (%)</td>
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<tr>
<td>Concession Price ($ Dollars)</td>
<td>Interest Rate (%)</td>
</tr>
<tr>
<td>Government Subsidy ($ Dollars)</td>
<td>Capitalized Interest Rate (%)</td>
</tr>
<tr>
<td>Equity (%)</td>
<td>Construction Period (Years)</td>
</tr>
<tr>
<td>Equity Ratio (%)</td>
<td>Construction Cost ($ Dollars)</td>
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<tr>
<td>Debt Ratio (%)</td>
<td>Inflation Rate (%)</td>
</tr>
<tr>
<td>Traffic Volume (Cars/day)</td>
<td>Tax Rate (%)</td>
</tr>
<tr>
<td>O&amp;M Cost ($ Dollars)</td>
<td>Discounted rate (%)</td>
</tr>
<tr>
<td>Debt Repayment ($ Dollars)</td>
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<td>Payment on Debt Interest ($ Dollars)</td>
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</table>

#### 3.3.3 System conceptualization

The approaches posited by several previous studies were considered in the current research, from model concept development to validation (Xu et al., 2012, Ke, 2014, Algarni et al., 2007, Ling et al., 2011). To illustrate the interdependent relationships between the PPP concession variables and assess the system feedback, we build a CLD (Figure 3). 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 better illustrate the relationship between the variables. The total project investment is a combination of debt and equity, and the more equity the project acquires, the less debt will be needed (Figure 3, B1). These equities can be divided into private and public equities. To fulfill the equity ratio, there is a tradeoff between private and
public equity values (Figure 3, B2). Also, debt and cash outflow have a directly proportional relationship. To curb against massive cash outflows, there is a need to consider more equity than debt in the capital structure (Figure 3, B4, B5 & B6). Besides, to maintain an appropriate value of NPV, the total cash inflows need to be higher than the total cash outflows (Figure 3, B7). To increase the total cash inflows, the traffic volume, and the concession price (user-payment) should be high. 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 (Figure 3, B8). Furthermore, a higher amount of 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 (Figure 3, 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 (Figure 3, B10 & R1).

Figure 3. Causal Loop Diagram.
3.3.4 Model formulation

In this section, several variables are included to power the model. The formulation of the model followed our previous research (Alghamdi et al., 2022). 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 pay by the private and or public partner towards funding the project.

3.3.4.1 Total Investment

The project’s total investment is defined as the summation of debt and equities (Figure 4) and can be expressed using the following formula:

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

\[
Debt = (1 - Equity) \times Capital\ structure \tag{2}
\]

\[
Equity = private\ equity + public\ equity \tag{3}
\]

Therefore, the equity ratio is given by:

\[
e = \frac{Equity}{Equity + Debt} \tag{4}
\]

Figure 4. Stock and flow diagram for total investment.
3.3.4.2 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 Figure 5.

![Figure 5. Stock and flow diagram for the Total Cash Outflows.](image)

To calculate the TCO, the following equations are considered:

\[
TCO_i = TCC_i + TOC_i \quad (5)
\]

\[
TCC_i = BC_i + EC_i + IC_i \quad (6)
\]

\[
BC_i = \begin{cases} 
    C 
    & \text{if } i \leq CP \\
    0 
    & \text{if } i > CP 
\end{cases} \quad (7)
\]

\[
EC_i = BC_i \times \left( \prod_{j=0}^{i-1} (1 + \tau_f) \right) \quad (8)
\]

\[
IC_{i-1} = (1 - E) \times BC_{i-1} \prod_{j=0}^{i-1} (1 + \tau_f) \prod_{j=0}^{CP-1} (1 + \tau_c)^{CP-1+1} \quad (9)
\]

Where; \( BC_i = \text{Base construction cost} \); \( EC_i = \text{Escalation cost or increase in cost due to inflation} \);
IC_i = Monetary value of capital interest on debt; CP = construction period; r_f = inflation rate;

r_c = capitalized interest rate; E = Equity; C = capital structure

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

\[ TOC_i = OMC_i + ADI_i + INT_i + TAX_i \] (10)

\[ OMC_i = \begin{cases} OMC_0 \times \prod_{n=0}^{i}(1 + r_f) & \text{if } i > CP, i \leq CP + OP \\ 0 & \text{if } i \leq CP \end{cases} \] (11)

\[ ADI_i = PR \times \frac{r^x(1+r)^RN}{(1+r)^{RN}-1} \begin{cases} & \text{if } i > CP \& i \leq CP + RN \\ 0 & \text{if } i < CP \& i > CP + RN \end{cases} \] (12)

\[ PR = \frac{(1-E)\times C}{RN} \] (13)

\[ Tax_i = (REV_i - INT_i) \times k \] (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

### 3.3.4.3 Cash Inflow

The Total Cash Inflow (TCI) during the concession period combines the total revenue generated and the monetary value of the subsidy injected during the operational year (Bian et al., 2021; Jin et al., 2020). 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 Figure 6. 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.
Figure 6. Stock and flow diagram for the Total Cash Inflows.

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:

$$Rev_i = 365 \times T_i \times p_i$$  \hspace{1cm} (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 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 the production of certain commodities. Indeed, not all PPP projects have subsidies. In case the government does not provide them, the second parameter in Equation 16 will evaluate to zero. The ultimate annual TCI will be equal to the total annual cash inflow for the year.

$$TCI_i = Rev_i + \frac{G}{OP}$$  \hspace{1cm} (16)
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 Equation 18. The opposite is true for when the traffic volume increases, which makes the model relevant regardless of demand uncertainty.

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

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

Where:

$p_o = \text{initial concession price}; r_f = \text{inflation rate}; T_o = \text{initial Traffic volume}; g = \text{growth rate}$

### 3.3.4.4 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 (Figure 7), and it is expressed as follows:

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

Where:

NPV = Net Present value

TCI = Total Cash Inflow

TCO = Total Cash Outflow

$d = \text{Discounting Rate}$
3.3.4.5 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 and is defined as the ratio of the profit before tax and the annual debt installment. The DSCR (Figure 8) can be calculated using the following formula:

\[
DSCR_i = \begin{cases} 
\frac{1}{RN} \sum_{t=0}^{RN} \frac{REV_t - TAX_t}{ADI_t} & \text{if } i \leq RN \\
0 & \text{if } i < RN 
\end{cases}
\]

(20)

Where:

- DSCR = Debt Service Coverage Ratio
- RN = Loan Repayment
- REV = Revenue
- ADI = Annual Debt Installment
3.3.4.6 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 satisfied, the project is more likely to attain its short- and long-term goals. The objective is to measure how sustainable the concession terms are designed to simultaneously maximize the return on investment and public interest. Recent studies have indicated that the public and stakeholders will be more confident to invest in every PPP setting and give a vote of confidence if their interests are protected, and investment returns are a key driver for effective PPP activities (Hodge and Greve, 2021, Lopez-Garcia et al., 2021). 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 level of importance. Weighting of the concession parameters is subjective and can be selected based on the importance of the parameter. Thus, the rule of thumb while determining the weights is that parameters with more
reasonable impact on sustainability, such as NPV, should be scored with bigger weights. The Socioeconomic sustainability indicator (Figure 9) can be calculated using the following formula:

\[
s = w_1 \times \frac{NPV}{NPV_{\text{max}}} + w_2 \left(1 - \frac{G_{\text{max}} - G_{\text{min}}}{G_{\text{max}} - G_{\text{min}}}\right) + w_3 \left(1 - \frac{OP_{\text{max}} - OP_{\text{min}}}{OP_{\text{max}} - OP_{\text{min}}}\right) + w_4 \left(1 - \frac{p_{\text{max}} - p_{\text{min}}}{p_{\text{max}} - p_{\text{min}}}\right) + \left(1 - \frac{\text{Equity} - \text{Equity}_{\text{min}}}{\text{Equity}_{\text{max}} - \text{Equity}_{\text{min}}}\right)
\]  

(21)

Figure 9. Stock and flow diagram for the Socioeconomic Sustainability Indicator.

### 3.3.5 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.
- 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 prices 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.
3.4 Model Validation

The US I-4, Ultimate PPP project, 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 6. 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 7 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.

Table 6. Model parameters for the I-4 Ultimate.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital structure</td>
<td>Billion dollars ($)</td>
<td>2.3</td>
<td>(PFAL, 2016; I-4 Ultimate, 2015)</td>
</tr>
<tr>
<td>Construction period</td>
<td>Years</td>
<td>6</td>
<td>(PFAL, 2016)</td>
</tr>
<tr>
<td>Equity Level</td>
<td>Percentage (%)</td>
<td>6</td>
<td>(PFAL, 2016)</td>
</tr>
<tr>
<td>Loan Capitalized interest rate</td>
<td>Percentage (%)</td>
<td>5</td>
<td>Assumed</td>
</tr>
<tr>
<td>Loan interest rate</td>
<td>Percentage (%)</td>
<td>3</td>
<td>Assumed</td>
</tr>
<tr>
<td>Traffic volume</td>
<td>Vehicle/day</td>
<td>70,000</td>
<td>Assumed</td>
</tr>
<tr>
<td>Discounted rate</td>
<td>Percentage (%)</td>
<td>5</td>
<td>(PFAL, 2016)</td>
</tr>
<tr>
<td>Tax rate</td>
<td>Percentage (%)</td>
<td>3</td>
<td>Assumed</td>
</tr>
<tr>
<td>Concession Period</td>
<td>Years</td>
<td>40</td>
<td>(PFAL, 2016; I-4 Ultimate, 2015)</td>
</tr>
<tr>
<td>Concession Price</td>
<td>Dollars ($)</td>
<td>9</td>
<td>Assumed</td>
</tr>
<tr>
<td>Total Subsidy</td>
<td>Billion Dollars ($)</td>
<td>0.4</td>
<td>Assumed</td>
</tr>
</tbody>
</table>
Table 7. Model validation results for the US I-4 Ultimate.

<table>
<thead>
<tr>
<th>Concession Period</th>
<th>Description</th>
<th>Operational Cost</th>
<th>Revenue</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>The beginning of the operation period</td>
<td>$138.1 M</td>
<td>$255.3 M</td>
<td>-$2.34 B</td>
</tr>
<tr>
<td>40</td>
<td>The endpoint of the concession period</td>
<td>$88.69 M</td>
<td>$583.8 M</td>
<td>$273 M</td>
</tr>
</tbody>
</table>

The dynamic behavior of the NPV, the DSCR, and the Socioeconomic sustainability indicator can be observed in Figure 10, Figure 11, and Figure 12, respectively. The results show that the NPV increases dynamically from negative to positive from the 8th year. The initial 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 simulation year increases, the NPV increases due to the revenue generated until it reaches a value of $273 million at the end of the concession period (Figure 10). The DSCR increases dynamically as the project generates revenue and repays its debt from the 8th year (Figure 11). The Socioeconomic Sustainability Indicator increases with the operational period (from 8.5 years onwards) as the project generates revenue (Figure 12).

![Net Present Value NPV](image)

Figure 10. The Dynamic NPV results for the I-4 Ultimate.
3.4.1 Sensitivity Analysis

3.4.1.1 Effects of changing a concession parameter on the other concession parameters

The sensitivity analysis aims to test 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 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.

3.4.1.1.1 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 ($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 8 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.

Table 8. Effects of changing the concession price on the other concession parameters.

<table>
<thead>
<tr>
<th>Concession Price ($)</th>
<th>6.3</th>
<th>7.2</th>
<th>8.1</th>
<th>9</th>
<th>9.9</th>
<th>10.8</th>
<th>11.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concession Period (years)</td>
<td>52</td>
<td>52</td>
<td>44</td>
<td>38</td>
<td>32</td>
<td>28</td>
<td>28</td>
</tr>
<tr>
<td>Equity (%)</td>
<td>7.8</td>
<td>7.8</td>
<td>6.6</td>
<td>5.4</td>
<td>5.1</td>
<td>4.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Subsidy (M$)</td>
<td>520</td>
<td>520</td>
<td>480</td>
<td>480</td>
<td>340</td>
<td>300</td>
<td>280</td>
</tr>
<tr>
<td>NPV (M$)</td>
<td>-520</td>
<td>-2.6</td>
<td>103</td>
<td>109</td>
<td>103</td>
<td>107</td>
<td>410</td>
</tr>
</tbody>
</table>
3.4.1.1.2 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 ($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 9 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.

Table 9. Effects of changing the concession period on the other concession parameters.

<table>
<thead>
<tr>
<th>Concession Period (years)</th>
<th>28</th>
<th>32</th>
<th>36</th>
<th>40</th>
<th>44</th>
<th>48</th>
<th>52</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concession price ($)</td>
<td>11.5</td>
<td>10.5</td>
<td>9.5</td>
<td>8.7</td>
<td>8.2</td>
<td>7.7</td>
<td>7.3</td>
</tr>
<tr>
<td>Equity (%)</td>
<td>7.8</td>
<td>6</td>
<td>5.7</td>
<td>5.4</td>
<td>4.8</td>
<td>4.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Subsidy (M$)</td>
<td>420</td>
<td>400</td>
<td>360</td>
<td>320</td>
<td>300</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>NPV (M$)</td>
<td>102</td>
<td>109</td>
<td>102</td>
<td>101</td>
<td>101</td>
<td>105</td>
<td>101</td>
</tr>
</tbody>
</table>

3.4.1.1.3 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 10 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.

| Table 10. 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 |

3.4.1.2 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 concession price (user-payment) was changed while the other concession components remained the same. The resulting dynamic behaviors are shown in Figure 13 and Figure 14. The results show that the more 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.
Figure 13. The NPV dynamic behavior for the concession price change.

Figure 14. The Socioeconomic Sustainability Indicator dynamic behavior for the concession price change.
3.5 Conclusions

This chapter aimed to build a novel socioeconomic 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 reverse change in the values of the other variables. For example, looking at Table 8, 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 ($100M).

Similarly, Tables 9 and 10 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 socioeconomic 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.
CHAPTER 4:

THE SOCIO-ECONOMIC MULTI-OBJECTIVE OPTIMIZATION APPROACH²

The participants of the Public-Private Partnership (PPP) projects have different parts in developing the concessions, hence, different perspectives and goals. Besides, the PPP concession agreement has many parameters and components, and a change in one component will have a considerable impact on the other components. Thus, determining the optimal value for different concession parameters by providing a series of feasible contribution options was investigated in this chapter using two different Multi-Objective Optimization (MOO) models; Genetic algorithm (GA) and Thompson Sampling (TS). Two case studies (The US I-495 and the I-4 Ultimate) were used to construct and validate the model results. The model results showed that the socio-economic sustainability performance increases as the private equity increases with a corresponding decrease in public equity. Furthermore, the socio-economic sustainability performance was inverse to the concession price (User-fee). The GA model obtained faster optimization results than the TS model; however, the TS obtained better results. Having these combination options could facilitate the decision-making process for both the public and private parties. Also, the use of the model could improve the socio-economic sustainability performance of the PPP project.

² The content of this chapter also appeared in:
4.1 Introduction

The need for mega infrastructure has increased over the last few decades due to the dramatically growing population living in big cities. Simultaneously, it may be hard for available infrastructure funds to meet the public needs with the growing demand (Azagew and Worku, 2020, Rodriguez-Pose and Griffiths, 2021). Building new infrastructures and maintaining existing others face insufficient public funds globally (Yun et al., 2009). Hence, the adoption of PPP agreements may be necessary to overcome these challenges. PPPs can overcome the public party's limitations in delivering services to the public. Not only that, but also redirect available public funds into more exceptional achievements for the nation. The PPP implementations have been increasing over the last few years, which indicates the importance of such contracts and approaches to the development of societies (PPIAF (Public-Private Infrastructure Advisory Facility) 2016).

A PPP may be seen as a constructed agreement involving some parties, a public party, and private parties to construct, renovate, maintain, manage, or operate a project that serves the public and private needs (Pereira et al., 2021, Pukhova et al., 2021). Some refer to it as a method for project funding, which can help overcome the public party's economic limitations via direct capital investment from the private parties in service establishment (Alinaitwe and Ayesiga 2013). PPP was mainly observed to tackle the public budget burden in delivering the needed social services and infrastructures (Li et al., 2005). Besides, these agreements aim to share risks and investments between the collaborated parties, significantly benefiting each party's achievements. Nevertheless, PPP has also offered the chance for private sectors to contribute to long-term agreements through the public sectors to sell their services and make profits in the long run, especially with the stable demand for public services.
On the other hand, designing a concession for PPP agreements is a complicated process due to the number of variables that need to be considered, affecting all participants in the concession agreement. The concession has many parameters and components, and a change in one component will considerably impact the other components. The concession components' fair values' determination needs to be based on mutual benefits between the concession participants. The concession participants have different parts in developing the concession; hence, they have different perspectives and goals. Therefore, the concession design needs to be constructed to balance the parties' interests to ensure smooth and sustainable development. One of the most significant aspects of successfully implementing PPP schemes is the adequate identification and balance between the involved parties' interests (Boyer and Newcomer 2015; Gordon et al. 2013; Gupta et al. 2013; Hwang et al. 2013; Wang 2015; Wibowo and Alfen 2015). Thus, the present study aimed to determine the optimal values of different concession parameters (concession period, concession price (User-fee), government subsidy, and capital structure (public and private equities)) when they are dependent on each other. It aimed to provide a series of feasible combination options. Then, a socio-economic sustainability performance indicator was calculated for each combination option. It is anticipated that having these combination options could facilitate the decision-making process for both the public and private parties, as recently opined in Radzicki (2020). Another aim is to compare between the GA and the TS MOO models.

4.2 Related Work

Many previous studies highlighted the importance of optimizing different concessionary components (Carbonara et al. 2014; Chen et al. 2012; Chou et al. 2012; Jasiukevičius and Vasiliauskaitė
These attempts have been conducted to optimize one aspect or another in the PPP implementation development. However, most of the studies focused only on one or two variables to optimize, while PPP projects have many variables, which differ from one another (Huang et al., 2021, Li and Strahan, 2021). Besides, optimizing one variable alone may reduce the optimal values for the other variables due to the interdependencies among the concession components. This section outlines the general research gaps based on available literature to justify further the current study’s aim of evaluating the effects and interplay of several interdependent socio-economic variables, which is important in giving a holistic perspective regarding effective long-term PPP.

### 4.2.1 Optimizing the Concession Period and Price

The main aim of selecting the concession period and price is to ensure a suitable revenue for private sectors to recover their capital investment (Shen et al. 2002). In most PPP cases, a twenty to forty-year concession period guarantees an adequate cash flow for the development costs repayment. This period is dependent on some economic and project factors, including the project type, concession price (User-fee), and the potential generated revenue, and therefore, it can be seen as a complicated decision-making process (Ullah et al. 2016). In most cases, private sectors may require long concession periods to reap enough revenue by collecting more user payments. In contrast, the public sector may require shorter durations to protect the public’s interest (Tariq and Zhang, 2021).

Practically speaking, the public party may determine the concession period before assigning the project to private parties (Zhang 2009). The public parties may be focusing on maximizing social
welfare, while the private parties may be focusing on maximizing their profits. Therefore, the decision for the concession period may be a complicated process (Liu et al., 2020, Silaghi and Sarkar, 2021). For example, by minimizing the concession period, public parties may have to issue large subsidies or large concession prices; hence, increasing their initial capital expenses or decreasing the level of social welfare. Therefore, balancing the levels of the concession period, price, and subsidies may be a critical decision process. From the private sector’s perspective, collecting more profits could be accomplished with either a high concession price and a low demand volume or a low concession price and a high demand volume. Therefore, a conflict of interest between the involved parties may be observed. Hence, all parties should work together to balance their interests in the concession agreement.

Concession price (User-fee), on the other hand, should be selected carefully by taking the public interest into considerations (Singh, 2021). The concession price is typically selected based on the society’s average per capita income to meet the public needs while ensuring an adequate users flow to increase the cash flow for generating the project’s revenue. It can be clear that the concession period and the concession price have an inverse relationship.

Many researchers have investigated modeling the concession period via different approaches, including the NPV calculations (Shen et al. 2002; Wu et al. 2011), game theories (Peng et al. 2014: 201; Shen and Wu 2005; Yang et al. 2007), besides simulation modeling (Carbonara et al. 2014; Ng et al. 2007a, 2007b; Ngee et al. 1997; Scandizzo and Ventura 2010; Yu and Lam 2013; Zhang 2009). However, the process of choosing the ideal concession period and price is complex, and it depends on several concession factors and components that may differ from one project to another. The concession price should be adequately large to cover the private party’s investment in short concession periods, and at the same time, it should be small enough to preserve the public’s welfare and ensure adequate user flow (Matsumoto et al., 2021). Alternatively, the concession period value
should be adequately long to ensure the payback of the private’s investments plus an adequate profit is accomplished with a low concession price, and at the same time, it should be short enough to ensure the public’s interests and social welfare are protected. Determining the appropriate values of the concession period and price will affect other related factors and concessionary items in the PPP contract. For instance, reaching an optimal value for the concession period will reduce the optimal value of the other concession factors. Therefore, a tool that considers several PPP concession’s factors simultaneously is needed due to the conflicting interests between the concession components.

4.2.2 Optimizing the Capital Structure

The capital structure can be seen in the project’s financing combination between debt and equity, indicating the total capital cost and the project’s value. Optimizing the capital structure can have significant benefits, minimizing the capital cost and maximizing the project’s value. Public and private parties can obtain an agreed-upon equity level in the PPP project’s capital structure. Public equity differs from the public Subsidy as it is a public investment in the project. The public party acts as an investor (equity holder) instead of a facilitator issuing subsidies. A public party’s participation in the concession’s capital structure as an equity holder should be large enough to attract more private competitors and simultaneously raise the project’s debt capacity. Nevertheless, it should be small enough to mitigate the likely risks associated with the given project and preserve sustainable social welfare. Public and private sectors may agree on an adequate equity level that satisfies each involved party (e.g., equity holders, the public sector, and the lenders). Determining the level of equity is critical in defining the project’s capital structure. Nevertheless, it is a challenging task due to the different views and requirements of the involved parties.
In general, financial models are used to create deterministic values for the appropriate level of equity for private parties (Bakatjan et al., 2003; Dias and Ioannou 1995). However, a recent study suggested that using these financial models to create such deterministic values may lack uncertainties associated with the project (Quitoras et al., 2021). Hence, deciding the adequate level of equity should not be based on these predetermined values as it may lead to unexpected loses and risks. Therefore, the adequate capital structure determinations should be based on feasible options for the participants to choose the adequate values. Many quantitative financial studies have been conducted in the field to examine the appropriate capital structure values. For example, some researchers investigated adequate capital structures using the Capital Asset Price Method (CAPM) (Dias and Ioannou 1995), the linear programming method (Bakatjan et al. 2003), and the Monte Carlo simulation method (Zhang 2005). Other researchers studied economic and financial feasibility (Chang and Chen 2001; Ho and Liu 2002; Ranasinghe 1996; Tiong and Alum 1997). It is worthy of mention that the Modigliani-Miller theory has been used for several decades for assessing the framework of capital cost and capital structure. However, one of its limitations is the assumption that all financial institutions and flows are insoluble, which has given rise to modified ones such as the Brusov-Filatova-Orekhova theory in the late 2000s (Brusov et al., 2021).

The ideal sharing ratio can be enhanced when all the involved parties balance their interests respectfully to their contribution to the actual contract. The public parties seek to smoothly implement the project sustainably while preserving public funds as much as possible; private parties’ interests must be met to ensure the continuous progress of PPP projects. However, optimizing the capital structure alone can negatively affect the other concession components, such as the concession period and price, due to the conflicting interests between the concession components.
4.2.3 Optimizing the Public Subsidy

Most of the projects operated under the PPP agreements make low profits due to the considerable current and future risks associated with such projects’ long lifespan. In this case, governments or public sectors should provide adequate financial subsidies for such poor profitability projects to make the project economically feasible for private sectors. These subsidies are essential due to such low profitability projects’ promising benefits to society’s sustainable development. In other words, from the private sector’s perspective, the needed infrastructure projects for social development may not see the light if the projects have no potential return on investment. Therefore, financial support from the public parties, such as subsidies and guarantees, is essential to attract private parties due to the PPP long lifespan and the risks associated with its uncertainties (Chen et al. 2012; Khmel and Zhao 2015; Kokkaew and Wipulanusat 2014; Shaoul et al. 2012).

The fundamental goal of public parties is current social welfare and adequately delivering the required infrastructures. It can be clear that public subsidies have an inverse relationship with the concession period and the concession price (Jin et al., 2020). The more value of subsidies issued by the public parties to the concession, the less period and price the concession will require to pay back its investments. Therefore, government subsidies may act as an effective tool to decrease the concession period and price. Alternatively, public parties can reduce their initial financial contribution to the project by elongating the concession period or increasing the concession price.

It can be clear that the public parties’ subsidies are also used to attract more private parties and enhance their competitiveness. However, preserving public funds and budget is as critical as attracting the participation of private sectors. Therefore, a tool that can balance all the involved parties’ interests is vital in PPPs’ scope.
In general, subsidies can be seen as a risk-sharing mechanism to balance both parties’ interests (Wibowo et al., 2012). However, determining the adequate amount of Subsidy is the challenging part. The Subsidy should be large enough to cover the potential losses that private sectors may face and act as a leverage tool for the public parties to increase such participation and competition. At the same time, it should be small enough to preserve the public budget and social welfare. Determining the right amount of financial subsidy will affect other related factors in the PPP contract. For instance, reaching an optimal amount of government subsidy will reduce the optimal value of other factors. Therefore, a tool that considers several PPP concession factors is needed due to the conflicting interests between the concession factors.

4.2.4 Optimizing the Socioeconomic Sustainability Performance

PPP projects are usually mega projects in their nature and are constructed over a very long lifespan; hence, the concept of sustainability performance should be considered when awarding such projects. Usually, the most focused dimension when dealing with PPP projects is the economic dimension, where all shareholders emphasize the project’s financial sustainability (Bennett 1998). This is for them to ensure that their initial capital investment is paid back with the expected profits. PPP can deliver infrastructures to achieve sustainable development growth from the sustainable socio-economic perspective when governments do not have enough funds. This may be very helpful, especially for developing countries, to develop sustainable growth by utilizing private investments and capital. Besides, PPP can also be seen as new business prospects for the private parties to invest and profit. Hence, private sectors may have the ability to improve their sustainable economic development by undertaking PPP projects (Owusu-Manu et al., 2020). On the other hand, social welfare should be protected when developing concession agreements. This can be accomplished by
lowering the concession price (User-fee), shortening the concession period, or reducing the government subsidy.

However, there is a clear need for quantitative methods to address PPP projects’ socio-economic sustainability performance. These quantitative methods need to take all the PPP participants’ contributions and expected outcomes into account to examine and improve the socio-economic performance outcomes because the participant’s contributions to the PPP projects substantially impact the concession and the socio-economic sustainability performance (Hussain et al., 2022, Nkurunziza, 2021). Every participant in the PPP agreement has different goals and expectations. Hence, taking these expectations into account and applying them to the long-term agreement may result in better socio-economic sustainability performance for the PPP projects.

4.3 Methodology

4.3.1 Model Construction

The model construction is based on the Discounted Cash flow (DCF) method. With the DCF, the investment assessment from both the public and private parties is based on potential costs and revenues. The future projection of cash flows is converted to today’s value to assess both parties’ investments. Therefore, the following formulas are utilized to construct the model.

4.3.1.1 Total Investment

The PPP project’s total investment may be described as the summation of the debt fund and the equity fund.

\[ INV = Debt + Equity \]  

(1)

Therefore, we can define the following:
Equity ratio: \[ \frac{\text{Equity}}{\text{Equity} + \text{Debt}} \]  \hspace{1cm} (2)

Debt ratio: \[ \frac{\text{Debt}}{\text{Debt} + \text{Equity}} \]  \hspace{1cm} (3)

The following formulas can calculate the ratios of public and private investment:

\[ '\alpha = \frac{\text{INV}_{pu}}{\text{INV}_{pu} + \text{INV}_{pr}} \]  \hspace{1cm} (4)

\[ '\beta = \frac{\text{INV}_{pr}}{\text{INV}_{pu} + \text{INV}_{pr}} \]  \hspace{1cm} (5)

\[ '\alpha = \text{ratio of public investment}, \quad '\beta = \text{ratio of private investment}, \quad \text{INV}_{pu} = \text{public investment}, \quad \text{INV}_{pr} = \text{private investment} \]

### 4.3.1.2 Cash Outflow

The total cash outflow (TCO) during the project can be separated into costs due to the construction and cost during the operational year. The total construction cash outflow (TCCO) is the summation of the estimated cost for construction (CC), an increase in cost due to inflation (EC), and the capital interest (IC).

\[ TCCO = \sum_{i=1}^{CP} (CC_{i-1} + EC_{i-1} + IC_{i-1}) \]  \hspace{1cm} (6)

\[ CP = \text{Construction period}, \quad i = \text{year} \]

In this work, the cost for construction all through the construction year will be assumed to be the same, therefore,

\[ CC_i = \frac{C}{CP} \]  \hspace{1cm} (7)

\[ C = \text{capital structure} \]

\[ EC_{i-1} = CC_{i-1} \left( \prod_{y=0}^{i-1} (1 + r_f) - 1 \right) \]  \hspace{1cm} (8)

\[ IC_{i-1} = (1 - E)CC_{i-1} \prod_{y=0}^{i-1} (1 + r_f)(1 + r_c)^{CP-i+1} \]  \hspace{1cm} (9)

\[ r_c = \text{capitalized interest rate on debt}, \quad r_f = \text{inflation rate at } y \text{ year} \]
The total construction cash outflow can be further simplified into the private sector’s construction cost and the public sector’s construction cost. This can be calculated by calculating their equities during the construction phase.

\[ TCCO_{e\,public} = \sum_{i=1}^{CP} e_{public} \times (CC_{i-1} + EC_{i-1} + IC_{i-1}) \]  

(10)

\[ TCCO_{e\,private} = \sum_{i=1}^{CP} e_{private} \times (CC_{i-1} + EC_{i-1} + IC_{i-1}) \]  

(11)

The cash outflow during the operational year consists of the operational and maintenance cost, the annual repayment of the debt, the payment on debt interest, and the taxation. The following equation computes the cash outflow during the operational year:

\[ CO_i = OMC_i + ADI_i + INT_i + TAX_i \]  

(12)

Where \( OMC = Operational\ and\ maintenance\ cost \)

\[ OMC = OMC_{CC} \times \prod_{h=0}^{i-1} (1 + r_f) \]  

(13)

Annual loan installment

\[
\begin{cases} 
ADI_i = PR \times \frac{r \times (1+r)}{RN \times (1+r)\times RN-1} & \text{(at interest payment year)} \\
0 & \text{(not paying loan interest anymore)}
\end{cases}
\]  

(14)

Interest on debt

\[
\begin{cases} 
INT_i = ADI \times (1 - (1+r)^{(RN-i+1)}) & \text{(at interest payment year)} \\
0 & \text{(not paying loan interest anymore)}
\end{cases}
\]  

(15)

\( PR = principal\ amount, \ r = interest\ rate, \ RN = Loan\ repayment\ period \)

Taxation

The taxation can be considered as the combination of the tax on sales and the income tax and can be calculated by the following equation:

\[ Tax_i = (PBIM_i - INT_i) \times k \]  

(16)
\[ PBIM_i = \text{Profit before deduction of interest}, \quad INT = \text{Interest on debt}, \quad k = \text{combined taxation on sales and income} \]

### 4.3.1.3 Cash Inflow

The Total Cash Inflow (TCI) can be generated from the project’s revenue. For example, the TCI for a toll-based PPP project is generated from public usage’s toll revenue. The TCI during an operational year depends on the demand for public usage and the concession price. Hence, the total revenue generated in an operational year can be calculated by the following formula:

\[
TCI = \sum_{j=1}^{N} T_o \times p \times \prod_{k=0}^{j-1} (1 + g) \tag{17}
\]

Here, \( T_o \) = Initial projected Average traffic volume, \( p \) = concession price, \( N \) = concession period, \( g \) = growth rate.

#### 4.3.1.4 Debt service coverage ratio (DSCR)

DSCR is a financial indicator used by loan lenders to measure the investment’s ability to recover the debt. In this work, DSCR is calculated by computing the average of the DSCR during the loan repayment period, and the following formula can compute it:

\[
\text{Avg DSCR} = \frac{1}{RN} \sum_{t=0}^{RN} \frac{PBIM_{t-\text{TAX}}}{ADI_t} \tag{18}
\]

### 4.3.2 Formulation of the Objectives function

This work presents a multi-objective function to maximize private and public interests. The objectives function is defined as follows:

1. Maximization of the investment of the private sector using the Net Present Value (NPV)
NPV has proven to be a financial indicator of the PPP project’s profitability regarding private equity. Net present value can be calculated using the formula below.

\[
NPV = -T_{CCO_{private}} + \sum_{t=0}^{N} (CI_t - CO_t + \frac{G}{op})(1 + i_A)^i
\]  

(19)

Where \( \sum_{t=0}^{N} (CI_t - CO_t + \frac{G}{op})(1 + i_A)^i \) indicates the net present value generated during the concession period, \( i_A \) is the discounted rate for the project, and \( N \) is the number of years in the concession agreement.

2. Maximization of public interest

While private investors focus on making profits, the public party’s priority is protecting public interests, including the social cost of public service usage and the amount of funds invested during the operational year. Therefore, to maximize the public interest, public funds are minimized.

\[f_2 = TCCO_{public} + G\]

Where \( G \) = Total Subsidy.

3. Minimization of the Concession period

The concession period should be short enough to ensure the public’s interests are met and social welfare is protected. A minimum concession period with a higher net present value can also attract private investors to venture into PPP.

4. Minimization of the Concession price

The concession price should be minimized to ensure meeting the public needs and, at the same time, ensure an adequate users-flow to increase the cash flow for generating the project’s revenue.

In summary, the objectives functions are:

1. Maximization of NPV, \( f_1 \)

2. Minimization of public expenditure, \( f_4 \)
3. Minimization of the concession period, $f_2$

4. Minimization of concession price, $f_3$

$$\max(f_1) \min(f_2), \min(f_3), \min(f_4)$$

Therefore, we can define the socio-economic sustainability indicator by balancing the objectives’ functions. The socio-economic sustainability indicator is a value obtained using a weighted summation of the objectives’ functions. Weighting is introduced to prioritize any objective function. In this paper, we define the socio-economic sustainability indicator as follows:

$$s = w_1 \times \frac{NPV - NPV_{min}}{NPV_{max} - NPV_{min}} + w_2 \left(1 - \frac{G - G_{min}}{G_{max} - G_{min}}\right) + w_3 \left(1 - \frac{OP - OP_{min}}{OP_{max} - OP_{min}}\right) + w_3 \left(1 - \frac{p - p_{min}}{p_{max} - p_{min}}\right)$$ (20)

Where $w_1, w_2, w_3, w_4$ are the weight of each optimization function according to their importance level.

The summation of the weights is equal to 1, $w_1 + w_2 + w_3 + w_4 = 1$.

$NPV_{max}, G_{max}, OP_{max}, p_{max}$ are the maximum expected net present value, subsidy level, operational time, and price.

$NPV_{min}, G_{min}, OP_{min}, p_{min}$ are the minimum expected net present value, subsidy level, operational time, and price.

### 4.3.3 Assumptions

The assessments of PPPs concessions involve projecting the future, following several assumptions and projections. The validation of the model is dependent on the correctness of the assumptions. The following assumptions are made in the model formulation:
The total investment is merely from the loan and the equity.

The loan is assumed to be obtained from a source with a capitalized interest during the construction and a current interest rate during the operational year.

The equity fund is invested at the time, t=0.

The concession price is considered the average toll charge for all users, increasing throughout the contract period due to 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.

### 4.4 The Multi-Objective Optimization Model

Due to the several objectives and conflicting interests between the private and public sectors involved in the PPP contracts, the ideal way to simultaneously address and optimize these objectives is through a Multi-Objective Optimization (MOO) model. MOO techniques have been widely used in the optimization research area nowadays due to their applicability to real-world problems.

Conducting such optimizations to several variables may acquire an optimum solution set, described as the Pareto optimal solutions, rather than a single optimal solution (Deb 2003). Developing the set of solutions will not give an optimal solution to each of the objectives; instead, there will be some trade-offs between the objectives’ optimal values (Figure 15). The goal here is to find the optimal solutions considering the trade-offs between the objective values. Therefore, decision-makers will have the ability to select a suitable set of solutions depending on the ideal level of trade-offs between the objectives based on the importance of each concessionary item.
The traditional solution to a multi optimization problem involves transforming the multi-objective functions into single objective functions by weighting the objective functions; this pays significant attention to minimizing cost using the global search failing to balance other decision variables.

The Multi-Objective Genetic algorithm (GA) and Thompson Sampling (TS) are introduced to solve the multi-objective programming problem in this work. The goal of both algorithms is to compute the parent optimal set, which is the non-dominated optimal solution. Both approaches have been used widely in the literature and have proven to be effective for providing solutions to complex systems that deal with trade-offs. These algorithms aim to compute the parent optimal set, which is the non-dominated optimal solution.

The Multi-Objective GA works similarly to the conventional GA, including the chromosome’s formation, the cross-over operations, mutations, and the selection process. However, the significant difference is in the selection process, which involves selecting Pareto dominance by selecting the fittest individual after considering all the objective functions. The structure of the GA Multi-objective functions can be seen in Figure 16.
On the other hand, TS Multi-objective optimization uses a stochastic approach by exploiting new solutions using randomness and selects the best solution using the probability of selection. The concept of Thompson sampling is sampling random numbers using the posterior distribution probability of the reward of the solutions. The TS structure can be described in Figure 17.

Figure 16. Genetic Algorithm Multi-Objective optimization structure.
4.5 The case studies

4.5.1 Case Study 1: The US I-495 Express Lanes

The US I-495 Express lanes are carried out by the Virginia Department of Transportation. This project can be seen in constructing two additional lanes in each direction of the congested I-495 highway road. The project company is obligated to design, construct, operate, and maintain express lanes. The data for the case study is shown in Table 11. The PPP contract’s concession period for the capital beltway express lanes is 80 years; therefore, 75 to 85 years will be considered in this work. The I-495 express lanes consider a dynamic toll pricing, which depends on the traffic volume. According to the project operator (Transurban), in 2013, the generated price per vehicle ranged between $0.25 - $9.75 (Gilroy 2013). For simplicity, this case study’s concession price is assumed to be in the range...
of $1 - $10 / Vehicle to travel the entire length of the project. The traffic volume of the capital beltway is estimated to be 225,000 vehicles per day. However, the toll charges are collected for the extra lanes on users that wish to avoid traffic congestion. Transurban reported in 2013 that the traffic volume for the busiest day on the extra lanes is 47,500 vehicles (Gilroy 2013). Hence, considering the annual growth rate from 2013 to 2020, the demand for the extra lanes in this study is assumed to be 45,000 vehicles/day with a future annual growth rate of 1%. According to a recent report that was prepared for the Center for Transportation Public-Private Partnership Policy at the George Mason University, the total maintenance cost for the I-495 express lanes is set to be $9.7 Billion, which can be seen in $7.2B O&M and $2.4B major maintenance (GMU 2019). Therefore, this case study’s annual maintenance cost is defined to be $ 9.7 B / OP.

Table 11. Data for the I-495 Express Lanes Project.

<table>
<thead>
<tr>
<th>Project data</th>
<th>Value range</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Value</td>
<td>$2.068 Billion</td>
<td>(Bolaños et al. 2017)</td>
</tr>
<tr>
<td>Construction period</td>
<td>5 years</td>
<td>(Bolaños et al. 2017)</td>
</tr>
<tr>
<td>Debt to equity ratio</td>
<td>55%-45%</td>
<td>(Bolaños et al. 2017)</td>
</tr>
<tr>
<td>Loan Repayment Period</td>
<td>35 years</td>
<td>(Bolaños et al. 2017)</td>
</tr>
<tr>
<td>Loan capitalized interest rate</td>
<td>5%</td>
<td>Assumed</td>
</tr>
<tr>
<td>Loan current interest rate</td>
<td>3%</td>
<td>Assumed</td>
</tr>
<tr>
<td>Discount rate</td>
<td>5%</td>
<td>Assumed</td>
</tr>
<tr>
<td>Forecasted daily toll</td>
<td>45,000 vehicles / day</td>
<td>Assumed</td>
</tr>
<tr>
<td>Total maintenance cost</td>
<td>$9.7 Billion</td>
<td>(GMU 2019)</td>
</tr>
</tbody>
</table>
4.5.2 Case study 2: The I-4 Ultimate

According to the I-4 Ultimate, the I-4 ultimate express lane is a Public-Private Partnership project which is about 21 miles road that connects Kirkman road to State road 434 (I-4 Ultimate, 2015). The project’s total estimated cost is $2.3 billion, including replacing 74 bridges, widening 13 bridges, and building 53 new ones. Furthermore, the project will reconstruct 15 major interchanges and provide four new express lanes to the center of I-4. The express lanes will be running in 2021, and they will be owned by the Florida Department of Transportation (FDOT). FDOT did not have enough cash to fund the project; hence, by having this P3 agreement, the state will construct the road to meet the public needs. In other words, the project would take about 27 years to complete without P3, while with P3, it will take less than seven years to complete. The tolls then will be used to fund more than half of the project during the 40 years contract (I-4 Ultimate, 2015). The tolls will be based on a dynamic toll pricing that varies based on demand and will be collected electronically, and the FDOT will determine the cost of the tolls. For simplicity, the concession price for this case study is set to be in the range of 5$ to 7.5$ for the passenger journey all through the road, which can be a realistic range based on similar projects around the I-4 ultimate. For example, to travel 7 miles on the 95 express lanes in Miami pay, passengers tend to pay from $0.5 - $10.50 (I-4 Ultimate, 2015). The daily demand around the I-4 Ultimatum is estimated to be around 200,000 vehicles (I-4 Ultimate, 2015). However, for a more conservative forecast, the daily demand for this study will be 70,000 vehicles/ day. The data for the case study is shown in Table 12.
Table 12. Data for the I-4 Ultimate Project.

<table>
<thead>
<tr>
<th>Project data</th>
<th>Value range</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Value</td>
<td>$2.3 Billion</td>
<td>(PFAL, 2016; I-4 Ultimate, 2015)</td>
</tr>
<tr>
<td>Construction period</td>
<td>6 years</td>
<td>(PFAL, 2016)</td>
</tr>
<tr>
<td>Debt to equity ratio</td>
<td>94%-6%</td>
<td>(PFAL, 2016)</td>
</tr>
<tr>
<td>Loan Repayment Period</td>
<td>40 years</td>
<td>(PFAL, 2016; I-4 Ultimate, 2015)</td>
</tr>
<tr>
<td>Loan capitalized interest rate</td>
<td>5%</td>
<td>Assumed</td>
</tr>
<tr>
<td>Loan current interest rate</td>
<td>3%</td>
<td>Assumed</td>
</tr>
<tr>
<td>Forecasted daily toll</td>
<td>70,000 vehicles / day</td>
<td>Assumed</td>
</tr>
<tr>
<td>Discount rate</td>
<td>5%</td>
<td>(PFAL, 2016)</td>
</tr>
<tr>
<td>Estimated OMC during the operational year</td>
<td>$50 million</td>
<td>Assumed</td>
</tr>
</tbody>
</table>

### 4.6 Results

Optimization is carried out within the lower and the upper bound of the decision variables and satisfies the equity constraints. The decision variables are the concession period, concession price, private equity, public equity, and Subsidy. The optimization was carried out so that the five objective functions were balanced. The Non-optimized solution was computed using the agreement from the two case studies from Table 13 to describe the optimization procedure’s effectiveness. The resulting non-optimized results are described in Table 14. The decision variables were specified within a predefined lower and upper bound (Table 15). Consequently, optimization tuning was carried out to determine the non-inferior combination of parameters compared with the non-optimized results described in Table 14.
Table 13. Decision Variables from the agreement terms.

<table>
<thead>
<tr>
<th>Decision Variable</th>
<th>I-495 Project</th>
<th>I-4 Ultimate Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concession period</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>Concession price</td>
<td>$10 / vehicle (average)</td>
<td>$6 / vehicle (average)</td>
</tr>
<tr>
<td>Private Equity</td>
<td>29%</td>
<td>3%</td>
</tr>
<tr>
<td>Public Equity</td>
<td>16%</td>
<td>3%</td>
</tr>
<tr>
<td>Government Subsidy</td>
<td>$409 Million</td>
<td>$500 Million</td>
</tr>
</tbody>
</table>

Table 14. Non-Optimized Results.

<table>
<thead>
<tr>
<th>Objective Results</th>
<th>I-495 Project</th>
<th>I-4 Ultimate Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Present Value (NPV)</td>
<td>$0.575 Billion</td>
<td>$0.637 Billion</td>
</tr>
<tr>
<td>Total Public’s Investment</td>
<td>$0.754 Billion</td>
<td>$0.577 Billion</td>
</tr>
<tr>
<td>Debt Service Coverage Ratio (DSCR)</td>
<td>1.843</td>
<td>1.288</td>
</tr>
<tr>
<td>Sustainability Level</td>
<td>0.739</td>
<td>0.683</td>
</tr>
</tbody>
</table>

Table 15. Decision variables for the two case studies.

<table>
<thead>
<tr>
<th>Decision variables</th>
<th>I-495 Project</th>
<th>I-4 Ultimate Project</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower Range</td>
<td>Upper Range</td>
</tr>
<tr>
<td></td>
<td>Lower Range</td>
<td>Upper Range</td>
</tr>
<tr>
<td>Concession period</td>
<td>75</td>
<td>85</td>
</tr>
<tr>
<td>Concession price</td>
<td>$1/vehicle</td>
<td>$10/vehicle</td>
</tr>
<tr>
<td></td>
<td>(average toll)</td>
<td>(average toll)</td>
</tr>
<tr>
<td></td>
<td>$5/vehicle</td>
<td>$8/vehicle (average</td>
</tr>
<tr>
<td></td>
<td>(average toll)</td>
<td>(average toll)</td>
</tr>
<tr>
<td>Private Equity</td>
<td>0.01</td>
<td>0.4</td>
</tr>
<tr>
<td>Public Equity</td>
<td>0.01</td>
<td>0.2</td>
</tr>
<tr>
<td>Government Subsidy</td>
<td>$400 Million</td>
<td>$800 Million</td>
</tr>
<tr>
<td></td>
<td>$400 Million</td>
<td>$800 Million</td>
</tr>
</tbody>
</table>
4.6.1 Optimization Results using the Multi-Objective Genetic Algorithm (GA)

The GA Multi-objective Optimization follows the conventional genetic algorithm, which encodes decision variables into genes to form a chromosome. A bit of string representation was used for the chromosome design in this work. The genetic search was carried out with the GA parameters in Table 16, resulting in 20 Pareto fronts being generated representing the best combinations of decision variables that resulted in optimum value. The Pareto front was obtained from the GA output at the last generation. The best 10 Pareto fronts that effectively balanced the objective functions were extracted from the front to represent non-inferior solutions. Tables 17 and 18 present the optimization results for the two case studies. The parent front’s average socio-economic sustainability level was computed and compared with the non-optimized result, indicating a higher sustainability level than the non-optimal results.

Table 16. GA Parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation</td>
<td>500</td>
</tr>
<tr>
<td>Population Size</td>
<td>20</td>
</tr>
<tr>
<td>Elite Count</td>
<td>5</td>
</tr>
<tr>
<td>Constraint Tolerance</td>
<td>0.000001</td>
</tr>
<tr>
<td>Functional Tolerance</td>
<td>0.000001</td>
</tr>
</tbody>
</table>
Table 17. GA Optimization results for the US I-495 project.

<table>
<thead>
<tr>
<th>Concession Period (year)</th>
<th>Concession Price ($)</th>
<th>Private Equity</th>
<th>Public Equity</th>
<th>Subsidy ($B)</th>
<th>NPV ($B)</th>
<th>Public Investment ($B)</th>
<th>DSCR</th>
<th>Socioeconomic indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>75</td>
<td>10.032</td>
<td>0.068</td>
<td>0.382</td>
<td>0.572</td>
<td>0.885</td>
<td>1.40</td>
<td>1.734</td>
<td>0.803</td>
</tr>
<tr>
<td>75</td>
<td>9.5</td>
<td>0.05</td>
<td>0.4</td>
<td>0.4</td>
<td>0.630</td>
<td>1.26</td>
<td>1.4582</td>
<td>0.826</td>
</tr>
<tr>
<td>84</td>
<td>11.437</td>
<td>0.135</td>
<td>0.315</td>
<td>0.563</td>
<td>1.842</td>
<td>1.242</td>
<td>2.647</td>
<td>0.84</td>
</tr>
<tr>
<td>78</td>
<td>9.931</td>
<td>0.384</td>
<td>0.066</td>
<td>0.587</td>
<td>0.296</td>
<td>0.729</td>
<td>1.795</td>
<td>0.637</td>
</tr>
<tr>
<td>75</td>
<td>9.503</td>
<td>0.13</td>
<td>0.32</td>
<td>0.443</td>
<td>0.516</td>
<td>1.13</td>
<td>1.5062</td>
<td>0.786</td>
</tr>
<tr>
<td>76</td>
<td>10.174</td>
<td>0.156</td>
<td>0.294</td>
<td>0.575</td>
<td>0.809</td>
<td>1.21</td>
<td>1.831</td>
<td>0.781</td>
</tr>
<tr>
<td>77</td>
<td>11.255</td>
<td>0.093</td>
<td>0.357</td>
<td>0.709</td>
<td>1.580</td>
<td>1.48</td>
<td>2.398</td>
<td>0.873</td>
</tr>
<tr>
<td>75</td>
<td>9.5</td>
<td>0.05</td>
<td>0.4</td>
<td>0.4</td>
<td>0.630</td>
<td>1.26</td>
<td>1.458</td>
<td>0.826</td>
</tr>
<tr>
<td>76</td>
<td>9.732</td>
<td>0.128</td>
<td>0.322</td>
<td>0.449</td>
<td>0.630</td>
<td>1.14</td>
<td>1.607</td>
<td>0.794</td>
</tr>
<tr>
<td>78</td>
<td>10.825</td>
<td>0.347</td>
<td>0.103</td>
<td>0.585</td>
<td>0.841</td>
<td>0.806</td>
<td>2.212</td>
<td>0.794</td>
</tr>
<tr>
<td>77</td>
<td>11.092</td>
<td>0.089</td>
<td>0.361</td>
<td>0.736</td>
<td>1.470</td>
<td>1.513</td>
<td>2.302</td>
<td>0.827</td>
</tr>
<tr>
<td>80</td>
<td>10.837</td>
<td>0.287</td>
<td>0.163</td>
<td>0.585</td>
<td>1.021</td>
<td>0.936</td>
<td>2.249</td>
<td>0.767</td>
</tr>
</tbody>
</table>

Average 0.796
Table 18. GA Optimization results for the I-4 ultimate project.

<table>
<thead>
<tr>
<th>Concession Period (year)</th>
<th>Concession Price ($)</th>
<th>Private Equity</th>
<th>Public Equity</th>
<th>Subsidy ($B)</th>
<th>NPV ($B)</th>
<th>Public Investment ($B)</th>
<th>DSCR</th>
<th>Sustainability indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>6.306</td>
<td>0.01</td>
<td>0.05</td>
<td>0.515</td>
<td>0.795</td>
<td>0.6439</td>
<td>1.3783</td>
<td>0.819</td>
</tr>
<tr>
<td>38</td>
<td>6.564</td>
<td>0.028</td>
<td>0.032</td>
<td>0.654</td>
<td>0.986</td>
<td>0.735</td>
<td>1.4748</td>
<td>0.779</td>
</tr>
<tr>
<td>39</td>
<td>6.837</td>
<td>0.048</td>
<td>0.012</td>
<td>0.8</td>
<td>1.15</td>
<td>0.832</td>
<td>1.5800</td>
<td>0.707</td>
</tr>
<tr>
<td>35</td>
<td>5.474</td>
<td>0.049</td>
<td>0.011</td>
<td>0.422</td>
<td>0.141</td>
<td>0.45</td>
<td>1.1406</td>
<td>0.799</td>
</tr>
<tr>
<td>38</td>
<td>6.306</td>
<td>0.01</td>
<td>0.05</td>
<td>0.515</td>
<td>0.795</td>
<td>0.644</td>
<td>1.3783</td>
<td>0.819</td>
</tr>
<tr>
<td>37</td>
<td>5.999</td>
<td>0.019</td>
<td>0.041</td>
<td>0.488</td>
<td>0.56</td>
<td>0.592</td>
<td>1.2931</td>
<td>0.805</td>
</tr>
<tr>
<td>36</td>
<td>5.775</td>
<td>0.026</td>
<td>0.034</td>
<td>0.468</td>
<td>0.412</td>
<td>0.555</td>
<td>1.2287</td>
<td>0.804</td>
</tr>
<tr>
<td>42</td>
<td>6.834</td>
<td>0.039</td>
<td>0.021</td>
<td>0.567</td>
<td>1.18</td>
<td>0.620</td>
<td>1.5184</td>
<td>0.782</td>
</tr>
<tr>
<td>42</td>
<td>7.033</td>
<td>0.047</td>
<td>0.013</td>
<td>0.636</td>
<td>1.34</td>
<td>0.67</td>
<td>1.5827</td>
<td>0.775</td>
</tr>
<tr>
<td>39</td>
<td>6.683</td>
<td>0.035</td>
<td>0.025</td>
<td>0.682</td>
<td>1.047</td>
<td>0.75</td>
<td>1.5128</td>
<td>0.755</td>
</tr>
<tr>
<td>43</td>
<td>7.093</td>
<td>0.047</td>
<td>0.013</td>
<td>0.586</td>
<td>1.392</td>
<td>0.621</td>
<td>1.5861</td>
<td>0.793</td>
</tr>
<tr>
<td>38</td>
<td>6.472</td>
<td>0.031</td>
<td>0.029</td>
<td>0.619</td>
<td>0.913</td>
<td>0.693</td>
<td>1.4425</td>
<td>0.784</td>
</tr>
<tr>
<td>39</td>
<td>7.5</td>
<td>0.046</td>
<td>0.014</td>
<td>0.518</td>
<td>1.438</td>
<td>0.553</td>
<td>1.6912</td>
<td>0.981</td>
</tr>
<tr>
<td>37</td>
<td>6.132</td>
<td>0.015</td>
<td>0.045</td>
<td>0.5</td>
<td>0.681</td>
<td>0.615</td>
<td>1.3284</td>
<td>0.824</td>
</tr>
<tr>
<td>41</td>
<td>6.712</td>
<td>0.032</td>
<td>0.028</td>
<td>0.555</td>
<td>1.088</td>
<td>0.626</td>
<td>1.4863</td>
<td>0.792</td>
</tr>
<tr>
<td>45</td>
<td>7.176</td>
<td>0.046</td>
<td>0.014</td>
<td>0.518</td>
<td>1.45</td>
<td>0.553</td>
<td>1.5922</td>
<td>0.8001</td>
</tr>
</tbody>
</table>

Average 0.80

4.6.2 Optimization Results using the Thompson Sampling (TS)

The TS was carried on the data; the first set creates random data sampling for inputs. The TS returned the parent font for the decision variables and the corresponding values for the objective functions. The optimization results for the TS for the two case studies are shown in Tables 19 and 20. The solutions of the parent front are not inferior to the agreement terms. The average sustainability level shows that the TS algorithm provides better optimal results when compared with the GA Multi-Objective optimization.
Table 19. TS Algorithm Optimization results for the I-495 Project.

<table>
<thead>
<tr>
<th>Concession Period (year)</th>
<th>Concession Price ($)</th>
<th>Private Equity</th>
<th>Public Equity</th>
<th>Subsidy ($B)</th>
<th>NPV ($B)</th>
<th>Public investment ($B)</th>
<th>DSCR</th>
<th>Sustainability indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>83</td>
<td>10.705</td>
<td>0.239</td>
<td>0.211</td>
<td>0.46</td>
<td>1.074</td>
<td>0.915</td>
<td>2.164</td>
<td>0.762</td>
</tr>
<tr>
<td>78</td>
<td>11.8</td>
<td>0.127</td>
<td>0.323</td>
<td>0.766</td>
<td>1.687</td>
<td>1.464</td>
<td>2.554</td>
<td>0.88</td>
</tr>
<tr>
<td>79</td>
<td>11.297</td>
<td>0.119</td>
<td>0.331</td>
<td>0.65</td>
<td>1.443</td>
<td>1.364</td>
<td>2.312</td>
<td>0.848</td>
</tr>
<tr>
<td>76</td>
<td>10.543</td>
<td>0.012</td>
<td>0.438</td>
<td>0.567</td>
<td>1.215</td>
<td>1.512</td>
<td>1.909</td>
<td>0.872</td>
</tr>
<tr>
<td>84</td>
<td>11.782</td>
<td>0.299</td>
<td>0.151</td>
<td>0.536</td>
<td>1.508</td>
<td>0.860</td>
<td>2.663</td>
<td>0.851</td>
</tr>
<tr>
<td>77</td>
<td>11.137</td>
<td>0.289</td>
<td>0.161</td>
<td>0.527</td>
<td>0.879</td>
<td>0.875</td>
<td>2.148</td>
<td>0.891</td>
</tr>
<tr>
<td>76</td>
<td>11.413</td>
<td>0.257</td>
<td>0.193</td>
<td>0.705</td>
<td>1.071</td>
<td>1.12</td>
<td>2.278</td>
<td>0.855</td>
</tr>
<tr>
<td>75</td>
<td>10.855</td>
<td>0.195</td>
<td>0.255</td>
<td>0.691</td>
<td>0.900</td>
<td>1.25</td>
<td>2.005</td>
<td>0.812</td>
</tr>
<tr>
<td>83</td>
<td>11.351</td>
<td>0.205</td>
<td>0.245</td>
<td>0.427</td>
<td>1.401</td>
<td>0.955</td>
<td>2.399</td>
<td>0.887</td>
</tr>
<tr>
<td>82</td>
<td>11.585</td>
<td>0.262</td>
<td>0.188</td>
<td>0.4</td>
<td>1.381</td>
<td>0.806</td>
<td>2.492</td>
<td>0.950</td>
</tr>
<tr>
<td>77</td>
<td>10.927</td>
<td>0.118</td>
<td>0.332</td>
<td>0.443</td>
<td>1.176</td>
<td>1.16</td>
<td>2.071</td>
<td>0.958</td>
</tr>
<tr>
<td>77</td>
<td>11.536</td>
<td>0.318</td>
<td>0.132</td>
<td>0.758</td>
<td>1.105</td>
<td>1.047</td>
<td>2.409</td>
<td>0.813</td>
</tr>
<tr>
<td>76</td>
<td>10.712</td>
<td>0.251</td>
<td>0.199</td>
<td>0.426</td>
<td>0.740</td>
<td>0.855</td>
<td>1.943</td>
<td>0.919</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>10.91</strong></td>
<td><strong>0.22</strong></td>
<td><strong>0.22</strong></td>
<td><strong>0.46</strong></td>
<td><strong>1.07</strong></td>
<td><strong>0.915</strong></td>
<td><strong>2.16</strong></td>
<td><strong>0.865</strong></td>
</tr>
</tbody>
</table>
Table 20. TS Algorithm Optimization results for the I-4 Ultimate Project.

<table>
<thead>
<tr>
<th>Concession Period (year)</th>
<th>Concession Price ($)</th>
<th>Private Equity</th>
<th>Public Equity</th>
<th>Subsidy ($B)</th>
<th>NPV ($B)</th>
<th>Public Investment ($B)</th>
<th>DSCR</th>
<th>Sustainability indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>6.205</td>
<td>0.031</td>
<td>0.029</td>
<td>0.46</td>
<td>0.860</td>
<td>0.534</td>
<td>1.324</td>
<td>0.776</td>
</tr>
<tr>
<td>35</td>
<td>5.824</td>
<td>0.043</td>
<td>0.017</td>
<td>0.402</td>
<td>0.297</td>
<td>0.446</td>
<td>1.231</td>
<td>0.88</td>
</tr>
<tr>
<td>38</td>
<td>7.3</td>
<td>0.021</td>
<td>0.039</td>
<td>0.766</td>
<td>1.459</td>
<td>0.868</td>
<td>1.696</td>
<td>0.919</td>
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<tr>
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<td>0.04</td>
<td>0.65</td>
<td>1.132</td>
<td>0.751</td>
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<td>0.862</td>
</tr>
<tr>
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<td>0.05</td>
<td>0.567</td>
<td>0.641</td>
<td>0.695</td>
<td>1.323</td>
<td>0.832</td>
</tr>
<tr>
<td>36</td>
<td>6.043</td>
<td>0.01</td>
<td>0.05</td>
<td>0.567</td>
<td>0.641</td>
<td>0.694</td>
<td>1.323</td>
<td>0.832</td>
</tr>
<tr>
<td>44</td>
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<td>0.024</td>
<td>0.536</td>
<td>1.546</td>
<td>0.597</td>
<td>1.624</td>
<td>0.927</td>
</tr>
<tr>
<td>37</td>
<td>6.637</td>
<td>0.037</td>
<td>0.023</td>
<td>0.527</td>
<td>0.872</td>
<td>0.587</td>
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<td>0.93</td>
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<tr>
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<td>0.705</td>
<td>1.067</td>
<td>0.773</td>
<td>1.592</td>
<td>0.91</td>
</tr>
<tr>
<td>35</td>
<td>6.355</td>
<td>0.028</td>
<td>0.032</td>
<td>0.691</td>
<td>0.743</td>
<td>0.773</td>
<td>1.445</td>
<td>0.827</td>
</tr>
<tr>
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<td>0.028</td>
<td>0.032</td>
<td>0.427</td>
<td>1.198</td>
<td>0.509</td>
<td>1.491</td>
<td>0.918</td>
</tr>
<tr>
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<td>0.501</td>
<td>0.996</td>
<td>0.539</td>
<td>1.438</td>
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</tr>
<tr>
<td>37</td>
<td>6.427</td>
<td>0.021</td>
<td>0.039</td>
<td>0.443</td>
<td>0.801</td>
<td>0.544</td>
<td>1.394</td>
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<tr>
<td>40</td>
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<td>0.612</td>
<td>1.357</td>
<td>0.679</td>
<td>1.615</td>
<td>0.934</td>
</tr>
<tr>
<td>35</td>
<td>6.769</td>
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<td>0.02</td>
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<td>0.918</td>
<td>0.724</td>
<td>1.550</td>
<td>0.909</td>
</tr>
<tr>
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<td>0.028</td>
<td>0.032</td>
<td>0.411</td>
<td>0.519</td>
<td>0.494</td>
<td>1.283</td>
<td>0.908</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>0.88</strong></td>
</tr>
</tbody>
</table>
4.7 Discussion

4.7.1 Comparison between the GA Optimization results and TS results

In the genetic algorithm (GA), the selection of the Pareto fronts is made using an elitist genetic algorithm in which GA favors some individuals than others due to better results from the evaluated result from the GA. On the other hand, with the Thompson sampling optimization algorithm, the best Pareto search is obtained by choosing some set of data points that gave the largest hypervolume indicator (the performance measure that is assigned a single value to the solutions obtained from the data points) (Trovo et al., 2020). The advantage of a genetic algorithm over the Thompson sampling algorithm is that it enhances faster optimization results; however, the Thompson sampling algorithm obtained better results than the Genetic Algorithm which coincides with the findings of Karamcheti et al., (2018).

The common ground between GA multi-objective optimization and Thompson sampling efficient optimization is that both algorithms begin by randomly initializing some set of data points (Touloupas and Sotiriadis, 2021). However, the genetic algorithm produces offsprings from parents through the cross-over operation and mutation, while in the TS algorithm, new data points are generated using sample functions from the Gaussian process. TS algorithm formulates m distinct functions from m independent Gaussian process using spectral sampling (Amrallah et al., 2021).

The TS algorithm obtained better optimization results than the GA; this can be confirmed by the average value of the parent fronts obtained from the results of the two algorithms. The TS algorithm determined the Pareto search from some sampled functions computed using the Gaussian process model for each objective function. The algorithm iterates to determine the best Pareto front by evaluating each objective function at every point to obtain the largest hypervolume until the
maximum iteration is reached (Bradford et al., 2018). In view of its potential applications in minimizing logistic bottlenecks, Dumitrascu et al. (2018) proposed an advanced TS algorithm, which agrees with the current study’s findings that the TS can be an effective tool to assess socio-economic status variables in viable PPP. In addition, our study is one of the first to compare both algorithm types within a PPP setting.

4.7.2 Statistical Analysis

Statistical analysis was carried using correlation to indicate the model’s significant parameters to improve the sensitivity analysis. The correlation measure used linear (Pearson) and rank (Spearman) methods to determine the most significant variable with the model’s greatest influence. The statistical results for the two case studies are shown in tables 21 and 22. It can be observed that the concession price and government subsidy have a significant influence on the socio-economic sustainability level for the first case study (USA I-495). In contrast, the concession price and period have the biggest parameter influence on the sustainability level for the second case study (US I-4 Ultimatum).

Table 21. Parameter Influence for the (USA I-495).

<table>
<thead>
<tr>
<th>Linear</th>
<th>Price</th>
<th>Private Equity</th>
<th>Public Equity</th>
<th>Subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0053849</td>
<td>0.50012</td>
<td>-0.063875</td>
<td>0.16297</td>
<td>0.63797</td>
</tr>
<tr>
<td>Rank</td>
<td>0.049081</td>
<td>0.48448</td>
<td>-0.037451</td>
<td>0.16168</td>
</tr>
</tbody>
</table>
Table 22. Parameter influence for the (I-4 Ultimate).

<table>
<thead>
<tr>
<th></th>
<th>Period</th>
<th>Price</th>
<th>Private Equity</th>
<th>Public Equity</th>
<th>Subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>0.84717</td>
<td>-0.933</td>
<td>0.32151</td>
<td>-0.30428</td>
<td>0.71993</td>
</tr>
<tr>
<td>Rank</td>
<td>0.65802</td>
<td>-0.61547</td>
<td>0.26618</td>
<td>-0.27074</td>
<td>0.54757</td>
</tr>
</tbody>
</table>

The partial correlation was also computed to determine how any two parameters controlled the socio-economic sustainability level. The concession period, concession price, private and public equity, and concession period subsidies are the matching parameters. Tables 23 and 24 show how the parameters controlled the socio-economic sustainability level. It can be observed that the equity level of both the private and public sectors has a significant influence controlling the socio-economic sustainability level.

Table 23. Parameter influence of two parameters to control sustainability for the (USA I-495).

<table>
<thead>
<tr>
<th></th>
<th>Period-price</th>
<th>Private equity-public equity</th>
<th>Period-subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>0.21942</td>
<td>-0.5172</td>
<td>0.16582</td>
</tr>
<tr>
<td>Rank</td>
<td>0.21042</td>
<td>-0.52423</td>
<td>0.1328</td>
</tr>
</tbody>
</table>

Table 24. Parameter influence of two parameters to control sustainability for the (I-4 Ultimate).

<table>
<thead>
<tr>
<th></th>
<th>Period-price</th>
<th>Private equity-public equity</th>
<th>Period-subsidy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>-0.33223</td>
<td>-0.4785</td>
<td>0.17297</td>
</tr>
<tr>
<td>Rank</td>
<td>-0.57166</td>
<td>-0.54397</td>
<td>0.40574</td>
</tr>
</tbody>
</table>
4.7.3 Sensitivity Analysis

The current study used sensitivity analysis techniques to evaluate how the model depends on the input parameters following previously described literature. The model was developed using MatLab functions. The model inputs are concession price, concession period, private equity, public equity, and government subsidy. The sensitivity analysis combined random and predefined data obtained from the optimized results. Fifty random samples within the bound of the decision variables were generated using a uniform distribution and were combined with the predefined data. The values generated for the case study were fitted into the objective function.

The mesh plot's sensitivity analysis results in this study indicate how the model depends on any two input parameters. The mesh plot is a 3-dimensional plot in which any two inputs can be combined to evaluate the level of dependence on the socio-economic level. Other parameters were set to fix while the two parameters were iterated between the lower and upper bound to develop the sensitivity analysis within any two parameters and the socio-economic level. Interestingly, this analytical tool has been used recently to assess variables for leakages in buried concrete sewage pipes (Zamanian et al., 2021), electromagnetic cardiac therapy (Levrero-Florencio et al., 2020), inkjet printhead troubleshooting (Nguyen et al., 2021), renewable energy appliances (Dezan et al., 2021), among others. The findings of our study pose important considerations for further exploration in the future regarding how a set of variables can interact at various complex levels to climax in a productive and cost-effective PPP in the long term.
4.7.3.1 Effect of Change of Concession Period vs. Change in Price

The sensitivity analysis between the concession period and concession price was presented in a 3D plot. Figures 18 and 19 describe the case studies’ surf plot by comparing the concession period and the concession price. The concession period was matched with the concession price to determine how the socio-economic sustainability level changes concerning the concession period and price. The sensitivity analysis results indicate that the concession price must be low while the concession period can be manipulated for a better socio-economic sustainability level. The results show that the project’s socio-economic sustainability performance is inverse to the concession price.

Figure 18. Effect of change in concession price and concession period on sustainability level for the US I-495.
4.7.3.2 Effect of change in Private Equity level and Public Equity level

The sensitivity analysis between private and public equity was carried out (Figures 20 & 21). It shows that a higher socio-economic sustainability level is obtained when the private equity is high, and the public equity is low. Therefore, the equity level must be maintained such that the private equity level is considerably higher than the public equity level. The project’s socio-economic sustainability performance directly relates to private and inverse public equity.
4.8 Conclusion

PPP is a long-term commitment involving several parties, including public, private, and lenders. When designing the concession, all parties’ interests must be satisfied to have a robust relationship between the involved parties. Their interests must be balanced optimally according to their contribution to the project, avoiding costly renegotiations or project failures. Besides, optimizing
interests between the involved parties may require some trade-offs. Therefore, the goal of the model presented in this paper was to help determine the optimal contribution ratios from each party by providing a series of feasible contribution options for several concession factors (concession period and price, government subsidy, and capital structure). Then a socio-economic sustainability performance was calculated for each combination. This paper presented a Multi-Objective Optimization (MOO) model constructed based on the Discounted Cash flow (DCF) method. The Multi-Objective Genetic algorithm (GA) and the Thompson Sampling (TS) were introduced to solve the multi-objective programming problem in this work. Case study 1 (The US I-495) was then utilized to construct and demonstrate the model. After that, case study 2 (The I-4 Ultimate) was used to validate the model results. The model helped to optimize the values for the different concession variables when they were dependent on each other. After that, the model presented different concession options containing different values for each of the concession components to help facilitate the decision-making process based on quantitative analysis. The GA model obtained faster optimization results than the TS model; however, the TS obtained better results. The model results showed that the socio-economic sustainability indicator increases as the private equity increases and the public equity decreases. The results also showed that the socio-economic sustainability indicator increases as the concession price decreases. Having these contribution options could facilitate the decision-making process for both the public and private parties. Besides, the use of the model could also improve the socio-economic sustainability performance of the PPP projects. The model presented in this paper can act as a valuable tool for both the public and private sectors in the bargaining process. It can also help reach mutual benefits between the involved parties based on quantitative analysis.
CHAPTER 5: CONCLUSIONS

This dissertation aimed to enhance the decision-making process on the PPP concession agreements from a Socio-Economic perspective. The first phase of this dissertation aimed to build a Socio-Economic System Dynamic (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 private and public equities. The second phase of this dissertation aimed to build a Socio-Economic Multi-Objective Optimization (MOO) model to help determine the optimal contribution ratios from each party by providing a series of possible values for several concession factors (concession period and price, government subsidy, and capital structure). Also, a Socio-Economic Sustainability indicator was provided to assess the Socio-Economic Sustainability Performance for both models. The utilization of both models helped answer the dissertation questions and address the hypothesis.

The System Dynamic model provided a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic 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 made the systems dynamic (SD) model suitable for application in the given PPP 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 method was that it did not include all the concession variables and critical indicators relevant to the infrastructure development sector.

On the other hand, The MOO model helped optimize the values for the different concession variables when they were dependent on each other. After that, the model presented different
concession options containing different values for each of the concession components to help facilitate the decision-making process based on quantitative analysis. The GA model obtained faster optimization results than the TS model; however, the TS obtained better results. The model results showed that the socio-economic sustainability indicator increases as the private equity increases and the public equity decreases. The results also showed that the socio-economic sustainability indicator increases as the concession price decreases. Having these contribution options could facilitate the decision-making process for both the public and private parties. Besides, the use of the model could also improve the socio-economic sustainability performance of the PPP projects. The MOO model could be a valuable tool for both the public and private sectors in the bargaining process. It can also help reach mutual benefits between the involved parties based on quantitative analysis.

However, both approaches had some limitations that needed to be considered. For example, the model’s validation depends on the accuracy of the model assumptions. Although the models had considered and investigated different concessions’ components, other critical concepts in the PPP agreements had not been fully implemented in developing the models.

The models also addressed the dissertation hypothesis:

- **H1**: When designing the PPP concession, there is a direct relationship between the Private Equity and the Socio-Economic Sustainability Performance of PPP projects.
- **H2**: When designing the PPP concession, there is an inverse relationship between the Public Equity and the Socio-Economic Sustainability Performance of PPP projects.

**Response**: The MOO sensitivity analysis between private and public equity was carried out (Figures 20 & 21). It shows that a higher socio-economic sustainability level is obtained when the private equity is high, and the public equity is low. Therefore, the equity level must be maintained
such that the private equity level is considerably higher than the public equity level. Thus, the project’s Socio-Economic sustainability performance directly relates to private equity and inverse to public equity.

- **H3**: When designing the PPP concession, there is an inverse relationship between the Concession Price and the Socio-Economic Sustainability Performance of PPP projects.

**Response:** The MOO sensitivity analysis results indicate that the concession price must be low while the concession period can be manipulated for a better socio-economic sustainability level (Figures 18 & 19). The results show that the project’s Socio-Economic sustainability performance is indeed inverse to the concession price.

- **H4**: When designing the PPP concession, the Concession Period is the most influential component on the Socio-Economic Sustainability Performance of PPP projects.

**Response:** The SD simulation results showed that the concession price (user-payment) has a major influence on the concession variables (Table 8). In addition, the MOO statistical results indicated that the Concession Price has the most influence on the Socio-Economic sustainability level (Tables 21 & 22). Therefore, the Concession Price is the most influential component and not the Concession Period.

### 5.1 Implications for the Industry

PPPs have many critical socioeconomic 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. Furthermore, PPP is a long-term commitment
involving several parties, including public sectors, private sectors, and lenders. Therefore, when designing the concession, all parties’ interests must be satisfied to have a robust relationship between the involved parties. Their interests must be balanced optimally according to their contribution to the project, avoiding costly renegotiations or project failures. Besides, optimizing interests between the involved parties may require some trade-offs.

The SD model provided a holistic perspective of the complex interplay between PPP effectiveness and several socioeconomic variables and was potentially valuable in facilitating and enhancing the decision-making process for PPP projects.

On the other hand, the MOO model helped determine the optimal contribution ratios from each party by providing a series of possible values for several concession factors (concession period and price, government subsidy, and capital structure). The proposed model aimed to simultaneously optimize the values for the different concession variables when they were dependent on each other. Having these contribution options could also facilitate the decision-making process for both the public and private parties.

Both models could act as valuable tools for both the public and private sectors in the decision-making and bargaining process to reach mutual benefits between the involved parties based on quantitative analysis. It is worth noting that PPP Projects are usually mega projects evaluated on a project-by-project basis. Therefore, the future implementation of the above models needs to be based on the specific project’s data and requirements.

Regarding the Socio-Economic Sustainability indicator, weighting was introduced in the equation to prioritize any concession parameter based on its level of importance. Weighting of the concession parameters is subjective and can be selected based on the importance of the parameter. Thus, the
rule of thumb while determining the weights is that parameters with more reasonable impact on sustainability, such as NPV, should be scored with bigger weights.

5.2 Future Research

This dissertation focused on the interdependent relationships between the critical concession variables to facilitate and enhance the decision-making process for PPP concession agreements. Some critical concession components (Concession Period, Concession Price, Government Subsidy, and Capital Structure) were considered; however, other components were not fully considered. Hence, future research can expand the models by including other critical concession indicators such as the impact of uncertainties, risk-allocation, interdependencies among other concession variables, handover mechanism, procurement approach, project refinancing at the end of the construction period, lifecycle assessment, and value for money.

On the other hand, from the sustainability perspective, the model has investigated some of the PPPs’ economic and social dimensions; however, different 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.

It is worth noting that PPP Projects are usually mega projects evaluated on a project-by-project basis. Therefore, the future implementation of the above models needs to be based on the specific project’s data and requirements.


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