# ABSTRACT

Title of Document: DESIGN OF AVAILABILTY PAYMENT MECHANISM FOR PUBLIC PRIVATE PARTNERSHIPS

Deepak Kanhaiyalal Sharma, Doctor of Philosophy in Civil Engineering, 2012

Directed By: Dr. Qingbin Cui, Department of Civil & Environmental Engineering

Availability Payment Public Private Partnerships (PPPs) are long-term contracts where the private sector is allocated responsibilities of designing, building, financing, operating and maintaining the highway on a public project. In return to their services the private sector is reimbursed through a performance-based predetermined payment plan. As per this plan, the private sector is entitled to receive predetermined payments called Maximum Availability Payments (MAPs) throughout the concession term (operations and maintenance phase). Thus the MAP amount and the length of concession term would have a major influence on the overall project cost since any inappropriate increase or decrease to these terms will heavily influence the project outcomes. This mandates the public agencies to diligently design MAPs and concession term but review of practices shows that the public agencies have been relying on unwarranted traditional methods to finalize these terms. Furthermore, very few researchers have worked towards designing the concession term and all the previous works have considered the payments and

concession term as independent variables. Last, the timing and cost of post-concession maintenance costs have never been considered before while designing payment structure and concession term.

This research work introduces a hybrid model developed by blending the stochastic dynamic programming model with multi-objective linear optimization principles that would allow the public sector to determine the upper limit of availability payments and concession term. This model ensures that public sector's cost saving objective and private sector's financial stability objective are satisfied simultaneously. The model also integrates post-concession maintenance cost structures and thus enables this model to include the effects of post-concession maintenance costs into the design. This model also allows inclusion of the effects of variation in private sector's financial condition and performance uncertainty in the design process. The research includes a case study focusing on Caltrans' Presidio Parkway Project and covers analyses that provide valuable insights about the design of Availability Payment PPPs. The analysis also quantifies and identifies the factors that affect payments and concession term in Availability Payment PPPs.

# DESIGN OF AVAILABILTY PAYMENT MECHANISM FOR PUBLIC PRIVATE PARTNERSHIPS

By

Deepak Kanhaiyalal Sharma.

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, College Park, in partial fulfillment
of the requirements for the degree of
Philosophy of Doctorate
2012

Advisory Committee:
Dr. Qingbin Cui, Chair
Dr. Steven Gabriel
Dr. Gregory Baecher
Dr. Shapour Azarm
Dr. Young Hoon Kwak

© Copyright by
Deepak Kanhaiyalal Sharma
2012

Acknowledgements

I take this opportunity to thank the Almighty for bestowing me with the intellect and enthusiasm that enabled me to complete my dissertation without much trouble.

I am extremely thankful to my advisor, Dr. Qingbin Cui, without whom I would not have completed this research. His unending support was instrumental in keeping me progressing even during the times of adversity. I feel extremely pleased and honored to have completed my PhD under Dr. Cui's guidance. I thank Dr. Steven Gabriel and Dr. Gregory Baecher for their valuable guidance and also for sharing their immense wealth of knowledge. I also thank Dr. Shapour Azarm and Dr. Young Hoon Kwak for kindly accepting to be on my committee and providing valuable suggestions.

I wish to thank all my friends who supported me directly or indirectly to complete this research work. I especially want to thank Mr. Deepak Agrawal whose help enabled me to automate the analysis and save enormous time. I also want to thank Mr. Venkataraman Santhanam and Mr. Jeremy Eckhause for their time and all the lengthy discussions which eventually enabled me to see the research problem from a unique perspective. I also thank all the students in Dr. Cui's Sustainable Infrastructure Group for being very encouraging and helpful. I express my deepest gratitude towards my parents and all other family members, whose sacrifices and love enabled me to complete this research work.

I would also like to thank Alabama Department of Transportation (ALDOT) and Civil and Environmental Engineering Department at University of Maryland, College Park for financially supporting my research.

## Table of Contents

## List of Tables

## List of Figures

# Chapter 1 Introduction

## 1.1 Introduction to PPPs

Public Private Partnerships (PPPs or P3s) have earned a reputation of a promising project delivery method around the world and are used by public agencies for developing public infrastructure. PPPs enable the public sectors to share risks and rewards in non-traditional ways with the private sector fostering possibilities of better project outcomes. Countries such as the United Kingdom, Australia, Canada, Ireland, India, Portugal, Spain, Turkey, Japan and several other countries have used different types of PPPs successfully to develop assets including, but not limited to, highways, metro rails, airports, bridges, hospitals, schools, prisons and water treatment plants (FHWA, 2007; Kwak et al., 2009; Parker, 2011). The global success of PPPs and the funding deficits paved the way for PPPs in the United States during the early 90s. Since then, PPPs have been increasingly used to deliver public infrastructure in the United States and investment in PPPs increased by five times between 1998-2007 and 2008-10 (Angel et al., 2011). In addition, the constantly increasing demand to add new roads and maintain aging infrastructure combined with the increasing financial deficits requires increased use of PPPs in the United States (Garvin, 2010; Mallett, 2008).

A PPP is a long-term contract between public and private sectors for mutual benefits. In the United States, PPPs are considered for project delivery when a proposed project's revenues streams are expected to be insufficient to meet all the financial obligations. For such projects, PPPs enable the public sector to pursue the project by involving private sector for filling the funding gap. Apart from financing, private sector is also required to take (or share) several responsibilities from the public sector. Depending on the private sector's investment, sharing of responsibilities and repayment method, the appropriate PPP type gets identified for the project. Commonly used PPPs in the United States include Design–Build (DB), Design–Build–Operate–Maintain (DBOM), Design–Build–Finance–Operate–Maintain (DBFOM), Build–Own–Operate (BOO), Long-Term Leases and Availability Payment PPPs (Abdel, 2007; FHWA, 2007b; Mallett, 2008; Kwak et al., 2009). Amongst these PPPs, the Availability Payment PPP is the newest type of PPP used in the United States.

The Availability Payment PPP is generally a DBFOM PPP. In these PPPs, the private sector takes the responsibilities of designing, building, financing, operating and maintaining the highway and is reimbursed only after the highway is available for use. The operations and maintenance phase of the project is generally known as concession period and the private party is known as concessionaire. The reimbursements are linked to the private sector's performance during the operations and the maintenance phase requiring the private sector to meet the performance standards as closely as possible. This motivates the private sector to construct the highway as soon as possible and then keep it available throughout the operations and maintenance phase, thus aligning public and private sector objectives. However, the literature review indicates that the PPP designs (that include Availability Payment PPPs) can take various forms depending on project requirements, and demands a more systematic approach to identify and evaluate the public interests in projects that use PPPs (GAO, 2008; Mallett, 2008). But, since the long-term PPPs are relatively new to the United States, the public sector seems to have inadequate qualification for evaluating and designing efficient PPPs (Garvin, 2010; Buxbaum & Ortiz, 2007). This dissertation focuses on Availability Payment PPPs and provides a hybrid model that would help address several concerns faced by PPPs.

## 1.2 Research Need

Federal- and State-level highway funds in the United States are finding it difficult to meet funding obligations for maintaining aging infrastructure and developing new (Mallett, 2008; Buxbaum & Ortiz, 2007; PEW, 2009; Silva & Lowy, 2011). In these harsh conditions, PPPs of various types have helped the public sector to deliver public projects. In particular, the use of Availability Payment PPP is believed to increase in the coming time (Parker, 2011). There are several inherent benefits of using Availability Payment PPPs, making them a preferred selection over other forms of PPPs. These benefits are:

One of the biggest benefits of using Availability Payment PPPs is the ability to turn a toll revenue supported infeasible PPP to a feasible PPP (FHWA, 2007b; Parker, 2011).

In case the PPPs (other than Availability Payments) are feasible, the private sector in today's economy, would want to reduce its road use demand risk by having a non-compete clause on the contract. This would prevent the public sector from making improvements to highways in the nearby region and might prove to be a disadvantage for the public interests (as it was observed in the case of SR-91 in California) (Czerwinski & Geddes, 2010). In the case of Availability Payment PPPs, since the private sector does not face road user demand risks, these clauses would not appear on the contract thus protecting public interests.

The public sector begins paying the private sector when the highway becomes available and continues paying the predetermined performance-based availability payments throughout the operations and maintenance phases. This form of payment mechanism reduces the public sector's responsibilities of arranging upfront capital finances, compels the private sector to meet all the performance standards to become eligible for earning availability payments without any deductions for substandard performance and helps the public sector cap the public sector expenses.

Furthermore, since the private sector is paid directly by the public sector, highways with Availability Payments are usually free from tolling which in turn increases the acceptability of PPPs on sociopolitical accounts (Garvin et al., 2011).

All these points suggest that considering the benefits of Availability Payment PPPs and the current financial condition, the use of Availability Payment PPPs (long-term performance-based concession PPPs, in general) would increase in the United States. Similar views are echoed by Buxbaum & Ortiz (2007) for long-term concession PPPs and the authors recommend using performance-based long-term concession PPPs (i.e., Availability Payment PPPs). The use of availability payments will enable achieving performance effectiveness as well as address public concerns regarding conflict of public and private sector interests.  However, recent findings by FHWA shows that agencies are striving to align their higher-level goals with performance measures of the PPPs, but none of the agencies have achieved them completely (Garvin et al., 2011). The FHWA also points out that the performance measures are prone to change with the passage of time and the public sector must plan for such a dynamic nature of the project.

In addition literature, the review also indicates that PPP designs (that includes Availability Payment PPPs) in the United States are influenced by the public sector's requirements to receive upfront payments from the private sector rather than achieving operational efficiencies (Bel & Foote, 2009; Czerwinski & Geddes, 2010). Examples of the Chicago Skyway and the Indiana Toll Road are undisputed examples that prove the public sector's history of using PPPs as a revenue generating mechanism. These have led to strong criticism and opposition towards the use of PPPs from several sections of society in the United States. In addition, PPPs where private sectors have filed bankruptcy (example: SR-125) or where private sectors have earned super profits (example: Chicago Skyway Project) or the private sector has gained excessive profits from a non-compete clause, (example: SR-91) all have contributed towards public burden through the use of PPPs. These projects have increased public skepticism over the public sector's decision-making abilities for selecting and designing PPPs that can protect public interests. In 2008, the Government Accountability Office (GAO) conducted a study that evaluated the protection of public interests while using PPP projects. In its report, the

GAO recommended that transportation agencies develop and conduct rigorous upfront financial analyses to protect public interests.

Addressing all these concerns, this dissertation focuses on design of availability payment mechanisms, enabling the public sector to achieve its performance requirements and making them safer to protect public interests. The predetermined annual payments that must be paid to the private sector for maintaining 100% availability of the highway, known as Maximum Availability Payment (MAPs), and the duration of the PPP contract, known as concession term, will be designed in this research work. This work distinguishes itself from the previous works since researchers have focused on design of concession or design of payment structure as separate problems. Ng et al. (2007a) and Ng et al. (2007b) used the Monte Carlo Simulation model and fuzzy logic for optimal design of concession period of PPPs. Mostafa et al. (2010) used Fuzzy-Delphi technique for designing the concession period under uncertainty. Shen J and Wang S (2010) used Perti Nets (a graphical method) to design the concession length. Shen and Wu (2005) have focused on designing the concession length of Build-Operate-Transfer (BOT) projects. Shen et al. (2007) and Nombela and Rus (2003) have similarly focused on negotiation of concession lengths and having flexibility of concession period respectively. Furthermore, none of the works have included the timing and amount of post-concession maintenance and rehabilitation costs into designs. This research work would also enable the public agencies to compare the project’s dynamic condition and would also enable them to find a solution to the problems.

As a result of this research the agencies would be able to design MAPs and concestion term simultaneously. Design of MAPs considering uncertainties in private sector's performance would protect public interests and would provide public sector with a reliable estimate of its financing obligations. Design of concession term would cap the public costs, provide adequate time to the private sector to get returns on its investment and also merge the post-concession scheduled maintenance costs into analysis.

## 1.3 Problem Definition

The public sector pursues a highway development project for meeting objectives such as relieving congestion or developing highways to attract industries or to cope up with the increased development in a region or any other reason that benefits the public. Although the project can benefit the region, the local funding agencies in the United States often do not have adequate funds for the project. In such conditions, PPPs are considered for the project delivery. The proposed PPPs can be supported through its estimated toll revenues if the estimated traffic is high; however, if the estimated revenue streams are weak, the Availability Payment PPPs are considered for the project delivery.

For Availability Payment PPPs in the United States, the competitive bidding approach is used to identify the private party, offering the best value or the lowest cost (Kessler, 2011). Generally, in practice, the best value approach is seen more often. For example, in the case of the Florida Department of Transportation's (FDOT) Port of Miami Tunnel and Access Improvement Project, the selection of the private sector was done using the best value approach. As a part of procurement process, FDOT disclosed its established limit of MAPs (which was actually the upper limit of MAPs) and also fixed the concession tenor (FDOT, 2006). The private sector was invited to bid on the project. The received bids were evaluated and the bidder Miami Access Tunnel (MAT) was found to offer the best value for the project. MAT was declared as the private party on the project and was allocated the responsibilities of designing, building, financing, operating and maintaining the project for 35-years. Such a contract where the majority of the responsibilities (generally long-term responsibilities) are given to a private sector is known as a concession and the private party that wins such a contract is known as a concessionaire. Being the concessionaire, MAT is required to design, construct, finance as well as maintain and operate the tunnel. Timely construction of the tunnel would enable the project to enter the operations and maintenance phase, marking the start of predetermined reimbursements known as Maximum Availability Payments (MAPs). To get 100% reimbursements, it would be necessary for MAT to operate and maintain the tunnel and achieve 100% availability of the tunnel. If MAT fails to achieve 100% availability, the MAPs would be reduced as per the penalties defined in the contract documents. A very similar approach was also used for the Presidio Parkway Project in California (Caltrans, 2010). These bidding practices (especially disclosing the MAP limits and fixing the concession term upfront) will continue since it is believed that limiting the MAPs and concession term would enable the public sector to compare and evaluate the bids.

It must be noted here that when the public sector discloses its capacity to pay MAPs and the concession term, they are not in a position to ascertain which private party will win the concession, what will be its construction efficiency, how the actual financial structure of the PPP will look like, and how efficient the private party will be during operation and maintenance phase of the highway. Hence, the public sector is forced to ignore these aspects and with the motive of getting the project delivered, proceeds with the bidding process. This process helps the public sector during procurement but leaves it vulnerable to several risks.

The limits on MAPs and concessions are determined considering the public sector's long-term societal objectives and funds available for the project. In addition, these decisions are made at a time when the public sector has no information about the private sector. Under these conditions the public sector can face the following risks:

1. The MAP limit offered by the public sector might be too high allowing the private sector to earn super profits.
2. Some private parties may submit very aggressive bids to win the competitive bidding. This could expose the project, the end-users and the public sector towards risks of major refinancing during the concession.
3. Every additional year of concession would allow the private sector to retain control over the asset and enjoy privileges which can go against the public interests.

4. If the concession term is shorter, the risk of private sector's failure due to not being able to get reasonable returns on its investment increases.
5. In addition, if the concession duration is shorter, the post concession highway maintenance costs would fall back on the public sector, which might not be beneficial for the end-users and the public sector.

In either case, it is a loss to the public. This could mean that the public sector might end up paying much more than it is required. This could lead to higher dissatisfaction amongst the people paying tolls and further increase in opposition towards PPPs. Hence, there is a need to develop a model that will enable public sector to:

1. Design MAPs allowing reduction in public sector's long-term expenses,
2. Design MAPs that can keep the private sector (still unidentified) motivated to stay in the PPPs even after facing uncertainties during the concession,
3. Design a concession term that enables the public sector to meet its long-term objectives (including post concession objectives) and
4. Design a concession term that would enable the private sector to earn reasonable returns from the project.

Achieving all the above objectives will not only ensure that the public sector objectives are met but will also ensure that the private sector earns at a reasonable rate of return. As a result, the public sector would be able to identify MAPs having smaller values. These MAPs would still offer enough opportunity to the private sector to earn at a desired rate of return.

### 1.4 Research Methodology

The issues discussed in the previous section justify a dedicated research towards design of the Availability Payment mechanism. The research process was divided into five major categories (see Figure 1) and these categories are briefly explained in the following paragraphs.

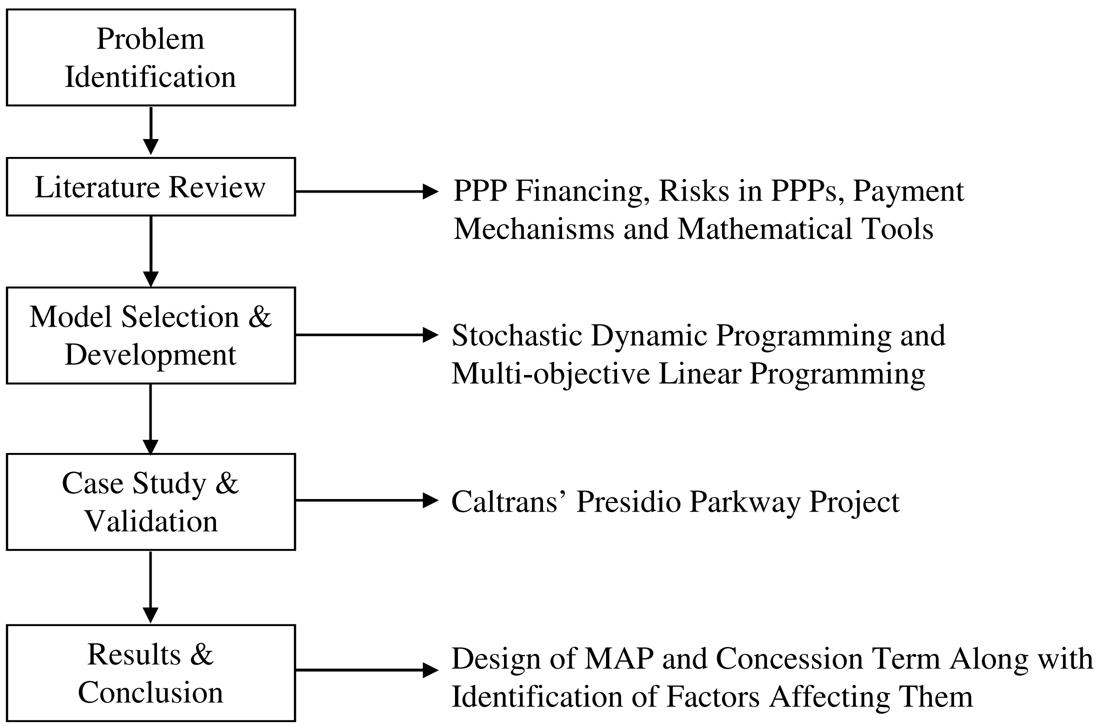


**Figure 1 Research Flow Chart**

### Problem Identification

The review of Availability Payment PPP projects in the United States led to the identification of the problems associated with these PPPs (as pointed out in Sections 1.2

and 1.3). This demanded identifying and understanding the root causes of these problems. Hence, an extensive literature review was conducted covering several areas.

**Literature Review**

The outcomes of Availability Payment PPPs, like all other types of PPPs, were found to be influenced by several project characteristics. Hence, the literature review was specifically focused to study effects and impacts of project finances; identification and evaluation of risks; and characteristics of Availability Payment PPPs. Review of all these topics helped in gaining a deeper understanding of the problems associated with Availability Payment PPPs. In addition to this, the literature review was also extended to learn about the mathematical models and concepts that were used during analysis and conclusion of this research work.

**Model Development**

The issues pointed out in Sections 1.2 and 1.3 required development of a model that could work as a prototype of the actual Availability Payment PPPs. This required that the model could:

1. represent long-term projects,
2. address all the uncertainties associated with the private sector,
3. include timing and costs of post-concession maintenance activities, and
4. simultaneously satisfy private and public sectors’ competing objectives.

Hence, a model was developed by blending multi-objective linear programming principles with a stochastic dynamic programming model. The model was developed to fit the stochastic dynamic programming model that conveniently enabled the model to capture effects of variations due to uncertainty in decision-making.

### Case Study and Validation

The California Department of Transportation's (Caltrans) Presidio Parkway Project was selected as a case study for this research work since majority of the information required in the model was readily available on the Internet. Although some of the details were not exactly as they were required as inputs to the model, the details were enough to be combined to develop all the information that was needed. In addition, since all the information from the private sector was not available, a few assumptions were made during this case study. The results were validated by developing the model as close as possible to the final agreement and then comparing the results.

### Conclusions

Results were obtained by running several models, each representing a certain project factor, which helped in reaching at several valuable conclusions.

## 1.5 Contribution

This research work introduces a method to design MAPs and concession term simultaneously. A hybrid model, formed by blending multi-objective programming principles with the stochastic dynamic programming model, is used in this research that will help design MAPs and concession term simultaneously by including the private sector's performance uncertainties in analysis. This work, for the first time, combines planning, construction, operations and maintenance and post-concession project costs in a single model for designing Availability Payment PPPs and thus sets up a stage for design of concession term based on the design life cycle of a highway.

This research also identifies and quantifies the factors affecting the design. The factors analyzed are private sector's performance, private sector's risk aptitude, private sector's construction efficiency and improvement in private sector's O&M efficiency. Three amongst these four factors are related to private sector's performance and hence this research work can be used to design performance-based Availability Payment PPPs rather than just designing finance based Availability Payment PPPs. Thus, this research work can help the public sectors to achieve the long-term performance-based objectives.

### 1.6 Organization of Dissertation

This research work is devoted to address all the issues discussed in Sections 1.2 and 1.3. This research work presents a multi-objective stochastic dynamic programming model that will enable the public sector to design a PPP's Availability Payment parameters. Use of this model will improve the overall efficiency of PPP projects. This dissertation presents a method to design Availability Payment mechanisms in a very structured way. Chapter 2 covers the literature review of PPP projects and Chapter 3 introduces the multi-objective stochastic dynamic programming model. Chapter 4 demonstrates the application of the model on the Presidio Parkway Project and designs the Availability Payments. Chapter 5 demonstrates the use of the model to design concession period and Chapter 6 includes analysis for identification of factors affecting Availability Payment parameters. Chapter 7 is the final chapter that summarizes and concludes this research work.

# Chapter 2 Review of Literature and Modeling Methodology

Availability Payment PPPs are dependent on factors such as project finances, deductions that reduce MAPs and the characteristics of Availability Payment PPPs. This chapter presents research work done in these areas that will enable establishing the existing gap in the body of knowledge. In addition to this, this chapter also introduces the mathematical methods used during this research work.

## 2.1 History of PPPs

PPPs have emerged as an indispensable tool for meeting infrastructure demands around the world. Countries like the United Kingdom, Australia and Canada have used PPPs extensively for developing infrastructure. In the United States, PPP programs are relatively new (FHWA, 2007). As per the "Report to Congress On Public Private Partnerships," the first turnpike was developed between Philadelphia and Lancaster in Pennsylvania in 1792. Between 1945 and 1955, several turnpikes were developed in the northern and eastern parts of the United States. These turnpikes were managed by public turnpike commissions or turnpike authorities that led to establish a belief in the people that providing highways was the responsibility of public agencies and the majority of them never thought of involving the private sector in developing highways. However, the public sector realized the increasing acceptance of peoples' willingness to pay tolls and have access to highways. The increase in demand of infrastructure and the drying up of funds from gas taxes led the State agencies to explore the potentials of involving the private sector in highway construction programs.

This led to the FHWA passing the Special Experimental Project 14 (SEP-14) that allowed the States to evaluate Innovative Contracting (which was later changed to Alternative Contracting in 2002) proposals, which would enable the public sector to transfer risks to the private sector (FHWA, 2009) in 1990. This was followed by passing of the Intermodal Surface Transportation Efficiency Act (ISTEA) just one year later, which enabled the use of tolls to greater extents, the private entities to own public facilities and the States to loan project costs to private entities (FHWA, 2004).

Since then, PPPs of various types have been employed for developing several highways in the United States. Literature review shows that over the past few years the use of PPPs has increased significantly. A survey conducted in 2008 reveals that 42% of the States planned to implement PPPs in the near future, 21% are currently practicing and 21% can be considered as experienced in PPPs (Cui & Lindly, 2010). The advantages that PPPs offer (Kwak et al., 2010; USDOT 2007) and the depletion of State and Federal funds (CBO, 2008) that used to fund highway development projects as well as the international success of PPPs indicates that use of PPPs will be necessary for the United States to keep up with the pace of increasing demand of new highways (FHWA, 2007).

### 2.2 Project Finances

Highway projects are financed through debts and if necessary the equity investment is allowed on the project. The process of arranging funds available through debts is called debt financing and the process of arranging equity on projects is called equity financing (Refer to Appendix 1 for additional details on the Debt and Equity Financing mechanism). When the project requires private equity investment but reimbursement through tolls cannot guarantee an adequate rate of return, the project is procured as an Availability Payment PPP. It must be noted here that the Availability Payment PPPs are pursued on the basis of a project's financial structure during procurement; hence, it is necessary to review the research work done towards financial structuring of PPPs. In addition to this, the concessionaire is paid availability payments throughout the concession period during which the concessionaire faces dynamic and uncertain conditions. These characteristics of Availability Payment PPP are used to develop a mathematical model in this research. Hence, a literature review was conducted to study the research done addressing issues related to project finances (especially equity cash flow) as well as structuring PPP finances.

The PPP financial structure is largely based on estimates of road-user demand, estimates of overall growth of the region, estimates of revenue generation and estimates of costs. Since the financial structure is dependent on all these estimates, a strong analysis is required to design it properly and ensure that public interests are protected. In 2008, the Government Accountability Office (GAO) conducted a study to evaluate PPP projects in terms of protecting public interests. The GAO pointed out that since the public sector in essence gives up control over a future stream of toll revenues in exchange for up-front payment concession, PPPs might not be warranted considering the uncertainties of traffic on these toll roads. It may happen that the net present worth of the exchanged future stream of toll revenues will become much larger than the up-front concession received. GAO recommended that transportation agencies develop and conduct up-front financial analyses to determine the benefits and costs of PPP agreements and to better deliver transportation infrastructure projects. Furthermore, NCHRP Synthesis 364 documents that only seven projects registered actual revenue streams within 10% of expected revenues (Kriger et al 2007). When the actual revenues are less than expected, the contractor may abandon the project or may declare bankruptcy. On the other hand, if the revenue streams are higher than expected, using PPP for project delivery can be questioned. In either situation the end users lose faith in the public sector's decision-making ability and in PPPs. The Indiana Toll Road and the Chicago Skyway projects are good examples of where the financial design of the PPP has let the government lose huge revenue streams (Cui & Lindly, 2010 and GAO, 2008).

Researchers have put forward accounts of various research works that can improve the setting up of financial structure for a PPP project. Vassalo (2010) evaluated the effect of government's use of established discount rate on the traffic risk profile. The author modifies the net present value equation, making several assumptions and after analysis recommends that the discount rate should never be more than the Weighted Average Cost of Capital (WACC). Lui and Cheah (2009) used real options for modeling the PPP structure for a wastewater treatment plant in China. The wastewater treatment plant's equity structure and shareholding system was redesigned to attract private investors to be involved in state-owned assets. Using real options methodology, a negotiation band was identified between the higher tariff rates and lower tariff levels. The area between these bands enclosed a range for mutually acceptable tariff rate between parties. The use of real options methodology helped to realize a larger feasible bargaining range between parties, which would prevent parties from getting into a negotiation breakdown stage. Power et al. (2009) also used Real Options to investigate feasibility and economic value of an option for the government to buy back the leased infrastructure at a future date prior to lease expiration. The authors used buyout options and revenue-sharing options in their study. The first option was modeled as the Bermudan call option and the second option was modeled as a sequence of European call options. The research shows that the inclusion of buyout or revenue sharing option will prove to be costlier for PPPs. Zhang (2005c) has used the optimization model to facilitate private and public sectors to conduct financial viability analysis and collectively determine an optimal capital structure. Zhang (2006) has put forward the use of a best value source selection (BVSS) methodology by using a set of best value contributing factors (BVCFs) for selecting the right private sector partner. The BVSS methodology allows for achieving maximum outcome from a business transaction. Using the BVSS methodology requires that the tenders be evaluated using multi-criterion evaluation methodology and the BVCFs are project specific so the BVCFs need to be tailored to reflect the public client's business needs.

Several researchers focused on guarantees offered by the public sector. Guarantees are used by governments to help private investors to recover from losses if the expected revenue falls below the expected levels. These guarantees must be designed with due diligence ensuring that the guarantees are high enough to make the project economically feasible and at the same time keep the guarantee levels low enough to not to burden the government and society in excess. A well-defined guarantee helps to attract private investors to invest in high-risk infrastructure projects. The results indicate that use of option-pricing methods can enable government to assess levels of guarantees, their impact on risk of the project and the expected value of the government outlays effectively. Brandao and Saraiva (2008) used a minimum traffic guarantee (MTG) real option model, which models a PPP with guarantees and helps put a cap on the total government outlays. On the other hand, Ashuri et al. (2010) used a Real Options methodology to design a Minimum Revenue Guarantee and a Toll Revenue Cap for PPP projects. The authors used a binomial lattice model of Real Options in this research. The authors included a case study of a highway between Incheon International Highway and Seoul and demonstrated the use of the proposed method.

### 2.3 Deductions in Availability Payment PPPs

Deductions are applied to the MAPs for non-availability of highway lanes (i.e., non-compliance with contractual conditions). These deductions can take any value ranging from zero and full MAP (Saage & Ajise, 2011). The amount of deduction depends on predetermined contractual conditions. The contractual conditions generally establish a rate of deduction for events that can contribute towards non-availability of highway lanes. The longer it takes to address the events leading to non-availability, the higher is the deduction. Hence, the concessionaire's operational and maintenance efficiency can have a direct effect on the deductions. So, a literature review was carried out to identify factors leading to obstruction of traffic on highways, and the time that might be required to address the issues obstructing the traffic, thus estimating deductions for the Availability Payment PPPs.

The literature review shows that factors that can contribute towards non-availability of the highway lanes are (Shin et al., 2002 and Shrank et al., 2010):

a. Crashes and Breakdowns

b. Weather

c. Regular and Periodic Maintenance (work zones)

Crashes and breakdowns affect the availability of highways. The availability of highway lanes depends on the severity of crashes. When the crash is very severe, more than one lane can be affected, which may result in the closure of multiple lanes. On the other hand, if the crash in non-fatal, the lanes may be unavailable for a relatively shorter period of time. The literature review shows that the lane closure information occurring due to crashes has not been documented directly, but the effect has been documented in terms of congestion and delay (Shin et al., 2002 and Shrank et al., 2010). The report documents that crashes caused 9 hours of average delay per driver in 1999. This report also stated that the information about breakdowns is scarce and estimates an average delay of 2.4 hours per driver.

Weather may create unfavorable conditions for smooth highway operations. Conditions like rain, snow, fog and ice may make the highway unusable for an unprecedented time. This affects availability of highway lanes and thus the deductions.

Periodic and regular maintenance is the last major factor that affects highway lane availability. Regular and periodic maintenance requires planning from the operating agencies (except for the maintenance jobs that require immediate response). Hence, the lane closures are documented by agencies and several researchers have studied the work zones for various works in several states (NCHRP Report 500 and Lindly & Clark, 2004). The information provided in these works can be used directly for calculating deductions for periodic maintenance. However, the regular maintenance activities are less time consuming and are much cheaper than periodic maintenance. Hence, the time and cost associated with regular maintenance is not considered when dealing with life cycle cost analyses (FHWA, 1998).

Each of the factors discussed above is uncertain and affects the availability of highways. If available, each of these causes must be included in the calculations of highway lane unavailability deductions. However, the detailed information on lane closure data (or estimates) is not available for each of these factors. Collecting or estimating this data will require dedicated efforts to collect, analyze and interpret data to estimate lane closures.

In addition to these factors, the private sector's operational and maintenance efficiency also plays a major role in the estimation of deductions. If the private sector is very efficient, the duration to address the events leading to deductions will be much less; however, if the private sector is not able (due to lack of resources or due to lack of experience) to address such events in time, the deductions can exceed up to the MAP for the term and also lead to termination of the concession.

The factors discussed above lead to deductions in Availability Payment PPPs. Combining all the effects from all these factors can provide valuable information about the deductions expected to be faced by the private sector. However, since the methods and data that could enable estimating deductions are not yet available, there exists a need for dedicated research to develop methods and/or processing data to estimate deduction.

### 2.4 Payment Mechanisms

The literature review of PPP projects shows that design of concession period has not yet grabbed much attention of researchers. The literature review shows that there are very few research articles addressing the issue of design of concession. Gross and Garvin

(2009) in their work have emphasized the need of structuring concession lengths and toll rates together. They have analyzed several PPP projects and concluded that by using the two variables together would allow both partners to perform better in terms of their risks and rewards. Ng et al. (2007) used the Monte Carlo Simulation model for optimal design of concession period of PPPs. In their model, the researchers used cost of designing, construction, operation, management and maintenance of facility, revenues and annual income as uncertain parameters. The model was developed to ensure that the private sector received reasonable returns rather than excessive returns and the public sector could reclaim the ownership of the facility at an appropriate time. The authors used normal and uniform distributions for the uncertain parameters and also used a hypothetical case study to demonstrate the use of the model. The authors also developed another model that used simulation and fuzzy logic to design concession in PPPs using the same hypothetical model (Ng et al. 2007 b). In this work, the authors developed the model for minimum expected investment and tariff regime.

On the other hand, Mostafa et al. (2010) used the Fuzzy-Delphi technique for designing the concession period under uncertainty. This method involved obtaining opinions of experts regarding the values of different parameters affecting the net present value of the project. After combining these opinions, fuzzy logic was used to design the concession period. In a similar way, Shen, J. and Wang, S. (2010) used Perti nets (a graphical method) to design the concession length. The authors modeled the problem to ensure that the investors got return on their investments and also ensure that the public sector got reasonable income. Shen et al. (2007) proposed use of the bargaining-game theory for negotiating concession lengths. The paper describes bargaining-game as the game where the players have common interest to cooperate but have conflicting interests over how to cooperate. The authors applied the model to the Dong-Fan Bridge and estimated the concession length to be between the range of 18.35 and 18.65 years. The game theory approach was also used by Ho (2006) to show when and how a government can rescue a distressed project and what impacts its rescue behavior had on project procurement and management.

Shen and Wu (2005) have researched to design the concession length of Build-Operate-Transfer (BOT) projects. The authors varied the net present value of cash flows to design concession lengths. The authors assumed normal distribution to simulate the uncertainty in NPV. Apart from this, the authors also used annual capital investment, annual traffic volume, toll price, construction time, annual maintenance costs and annual discount rate in the model. Nombela and Rus (2003) proposed the use of flexible terms in PPP projects and showed that having a fixed concession period does not yield optimal outcomes. The authors recommended using flexible concession periods for PPP projects.

### 2.5 Decision Support Tools

Several decision support tools and models have been developed by various agencies worldwide that help in decision-making. These tool and models focus on different aspects of PPPs (including Availability Payment PPPs) and enable the public sector to improve the outcomes. This section provides information about several such tools and models used around the world.

The World Bank developed a PPP toolkit named Toolkit for Public Private Partnerships in Roads and Highways (PPIAF, 2009). It consists of six modules that address choosing the right PPP, tailoring PPPs to fit its environment, protection of public interests, legal and regulatory issues, implementing and monitoring PPPs at project level. The United Kingdom uses an HM Treasury's spreadsheet model for conducting Value for Money assessment. India has developed its own online PPP Toolkit that can be used by the PPP community to make decisions needed to plan, develop and carry out successful PPPs (Government of India, 2010).

The Texas Department of Transportation (TxDOT) has developed an MS Excel based Public-Private Partnership (PPP) feasibility toolkit model named as TxDOT Public-Private Feasibility Analysis Model. Texas DOT has also developed a second MS Excel based toolkit called a Toll Viability Screening Tool that is used to determine the viability of toll roads during the preliminary stages (TTI, 2004). Alabama DOT recently started using an MS Excel based Toolkit called P3FAST (PPP Feasibility Analysis Toolkit) that enables conducting feasibility analysis and optimally design financial structure of the project (Cui et al., 2010).

Apart from these toolkits and models, several other works can be referenced here that can be used to improve PPP outcomes. Zhang (2005b) identified several criteria for selecting a right private-sector partner and differentiated them into four different packages. Sharma et al. (2010) developed a Linear Programming model to optimally structure PPP finances. Asmar et al. (2009) in their work provided a methodology that can be used to select the best alliance team for Design Build/Alliance project delivery systems for PPPs. In their work, the authors used the Monte Carlo simulation to consider uncertainty in variables.

Zhang (2009) used fuzzy logic considering the best value approach to select the best concessionaire. The best value approach is defined "as a set of systematic government procedures for the acquisition of public works and services, with an aim to achieve the best value (i.e., the maximum possible outcome) from such acquisition (NCPPP, 2002). In this work, the author tries to achieve two goals: 1) establishment of a set of cost- and non-cost evaluation criteria that can effectively measure the concessionaire's capability and predict its future performance toward achieving the government's best value objectives (BVOs) and 2) the development of a sound selection method ensuring a balanced tradeoff between these two criteria. In this work, the author achieves the first objective by defining a four-package evaluation criteria that includes: 1) financial (includes 35 elements), 2) technical (includes 26 elements), 3) safety, health and environmental (includes 15 elements), and 4) managerial (includes 16 elements).

Zhang (2009) also established a systematic approach to establish appropriate criteria for concessionaire selection that can be summarized as: 1) a study of the worldwide practices in concessionaire selection in terms of bidding processes, evaluation criteria, and selection methods; 2) a review of the very limited literature on concessionaire selection; 3) interviews and correspondences with international PPP researchers and practitioners;

and 4) further analysis, distillation, systematic coding and grouping of the evaluation criteria through a knowledge mining process of the information obtained in stages 1-3. The second objective was achieved by developing a fuzzy model. This method required scoring of evaluation packages by experts, which help in determining the weights for analysis. The author also used a 0 to 5 scale to determine the rate of significance of each criterion within each package. Although it is felt that this approach can be used to select the best project delivery, the method appears to be time consuming, costly and requires participation from experts of various fields. Furthermore, the method includes uses scoring by experts, which will include subjectivity in the analysis. Zhang et al. (2007) also presented a method to select concessionaire. In this analysis, the authors used the Kepner-Tregoe decision analysis technique.

McCowan and Mohamed (2007) developed a Decision Support System (DSS) that can be used to evaluate and compare different PPP projects. This paper provides mathematical background that can combine all the financial and non-financial factors together, which can be used to make decisions. The authors used the method to identify the best project from three identified projects.

### 2.6 Review of Mathematical Methods

Since the Availability Payment PPPs are long-term projects, face uncertainties and have competing and conflicting objectives, the stochastic dynamic programming model and multi-objective linear programming models were used in this research work. These models were blended to develop a hybrid model to model Availability Payment PPPs and hence a review of these methods is included here. These methods will be discussed in detail in Chapter 3.

### 2.6.1 Stochastic Dynamic Programming

Stochastic Dynamic Programming (SDP) models are used to obtain solutions to several optimization problems. The stochastic dynamic programming model has been used since the PPPs during the operation and maintenance phase satisfy Bellman's Principle of Optimality - "An optimal policy has the property that whatever the initial state and the initial decisions are, the remaining decisions must constitute an optimal policy with regard to the state resulting from the first decision"(Benli 1999).

While using the SDPs, the problems are broken down into several stages, which makes them a good modeling method to represent long-term Availability Payment PPPs. SDPs in general should have the following properties (Winston, 2004):

1. The SDP problem can be divided into stages with a decision required at each stage.
2. Each stage has a number of states associated with it.
3. The decision chosen at any stage describes how the state at the current stage is transformed into the state at the next stage.
4. Given the current state, the optimal decision for each of the remaining stages must not depend on previously reached states or previously chosen decisions.

5. If the states for the problem have been classified into one of T stages, there must be a recursion that relates the cost or reward earned during stages *t, t + 1, …. ,* T to the cost or reward earned from stages *t + 1, t + 2, …* , T. In essence, the recursion formalizes the working-backward procedure. Mathematically a recursion formula for SDPs can take be expressed as

$$f_t(i) = \underset{a}{min.} \left\{ (expected\ cost\ during\ stage\ t|i, a) + \sum_j p(j|i, a, t) f_{t+1}(j) \right\}$$

(2.1)

Where,

$f_t(i)$ = minimum costs during stages *t, t + 1, …* end of the problem given that the state at the beginning of stage *t* is *i*.

$p(j|i,a,t)$ = probability that the next period's state will be *j*, given that the current (stage t) state is *i* and action *a* is chosen.

The use of SDPs brought its own share of advantages and disadvantages to this research. The biggest advantage of employing SDPs in this research was from its similarity and simplicity in solving linear and non-linear optimization problems. However, solving SDPs may increase the computational burden significantly and may make it difficult (in some cases) to obtain a solution in a reasonable time frame.

SDPs have been used in various fields where decisions at different stages could make a difference toward the success of processes. Eckhause et al (2009) used a SDP to enable public sector acquisition managers to determine optimal vendor selection strategies. Tereso et al., (2003) used SDPs to allocate resources under stochastic conditions for multi-modal activity networks. Gabriel et al., (2004) used SDPs to determine optimal power load estimates for electric power retailers. Chiara et al., (2007) developed a multi-least squares Monte Carlo method using real options and dynamic programming frameset to support a highly flexible contract that would enable dealing with revenue risks for Build-Operate-Transfer PPP.

### 2.6.2 Multi-objective Linear Programming

Construction projects require participation of various parties and generally it is observed that the parties compete with each other for gaining and increasing their benefits. Unfortunately, a similar situation is observed in all types of PPP projects. The public sector wants to reduce its expenses towards the projects and the private sector wants to increase its earnings. If decisions are made just to satisfy the public sector's expense reduction objective, the project might lose its potential to attract the private sector to bid and continue on a long-term PPP project. On the other hand, if the private sector is able to gain very high profits, the use of PPPs might not get public approval in the future.

A multi-objective linear programming can be defined as (Gabriel, 2006a; Sahakij, 2008)

Minimize $\{f_1(x), f_2(x), f_3(x) \ldots . f_k(x)\}$

Subject to (2.1)

$x \in S \subseteq N$

where,

$f_1(x), f_2(x) \ldots, f_k(x)$ are linear objectives functions to be minimized

S is the feasible region defined by linear functions

N represents real numbers.

The multi-objective linear programming model can be solved by two different ways: 1) Constraint Method and 2) Weighting Method.

1) The Constraint Method

Solving the optimization problem 2.1 using the constraint method would require that the objective function be turned to a single-objective optimization problem and all the remaining objectives be treated as constraints. This would transform 2.1 to a new form as shown below (Sahakij, 2008):

Minimize $f_h(x)$

subject to (2.2)

$x \in S$

$f_p(x) \leq U_p, \quad p = 1, 2, \ldots, h - 1, h + 1, \ldots, k$

In the above formulation, the objective function $f_h(x)$ can be arbitrarily selected from the list of objectives that must be minimized. The remaining objectives take the form of linear constraints represented by $f_p(x) \leq U_p$.

2) The Weighted Method

Use of the weighted method would require that the objectives in the objective function of formulation 2.1 be multiplied by weights as shown below (Gabriel, 2006a; Sahakij, 2008):

Minimize $\sum_{i=1}^{k} w_i f_i(x)$

subject to (2.3)

$x \in S$

$\sum_{i=1}^{k} w_i = 1$

$w_i \geq 0; \quad i = 1, 2, \ldots, k$

The optimization problem 2.3 is linear and can be easily solved using existing methods and tools. In must be noted here that if one objective is assigned high-valued weight, the solution 2.3 would give more importance to the objective having higher weight. Furthermore, the weights largely depend on the utility function of the decision-makers and the decision-makers must select weights with caution when using MOLP.

Since the MOLP allows inclusion of several objectives in a single optimization problem, it is difficult (rather, it is impossible) to get "a solution" that would satisfy all the stakeholders. In such cases, an improvement in one of the objectives comes at an expense of at least one of the other objectives (Gabriel, 2006b; Cohon, 1978). Such a condition can be expressed by using the concept of Pareto Optimality, which can be expressed mathematically as shown below (Edgeworth, 1881; Pareto, 1896; adopted from Gabriel, 2008):

"A decision vector x* □ S is Pareto optimal if there does not exist another vector x □ S such that $z_i(x) \leq z_i(x^*)$ for all i = 1,2,…., k and $z_j(x) < z_j(x^*)$ for at least one index j".

The above definition can be explained used the following figure:

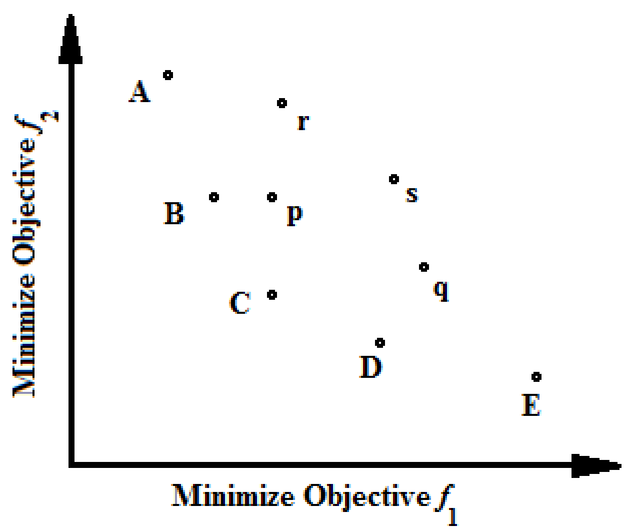


**Figure 2 Illustration for Pareto Optimal Set**

Figure 2 represents a Pareto Optimal set where both the objective functions are to be minimized. Hence, the points lying towards the south-west direction would be a part of the Pareto Optimal surface. In the above figure, points A, B, C, D and E fall towards the south-west direction of the feasible region and hence represent the Pareto Optimal curve. The points p, q, r and s are inferior to the points A, B, C, D and E and hence do not fall on the Pareto Optimal Curve.  The decision-makers must select an appropriate point on the Pareto Optimal Curve that would represent their utility in the best possible way.

Multi-objective Linear Programming (MOLP) has been used in situations where stakeholders have competing objectives. Researchers have used multi-objective programming to satisfy several objectives in several fields. Gabriel et al., (2007) used a multi-objective optimization model to minimize the odor of the bio-solids while at the same time trying to minimize the treatment and distribution costs. Gabriel et al., (2006a) used a multi-objective optimization model to prioritize selection of projects in a portfolio. The authors considered project value, managerial labor (input) needed, and average costs as objectives. In another work Gabriel et al., (2006b) used a multi-objective optimization model to minimize overall cost of portfolio of projects while maximizing the total value from the projects. Nair and Miller-Hooks (2009) used multi-objective programming model to maximize coverage of the emergency medical service fleet while minimizing its overall operation costs.

## Chapter 3 Model for Availability Payment Design

Previous chapters provide details about the current practice adopted by public sectors when using Availability Payment PPPs. Extensive literature review shows that although the use of long-term PPPs, including Availability Payment PPPs, is expected to increase in the near future, PPP professionals do not have a method to design Availability Payment PPPs. Since MAPs and concession term are the most important parameters in Availability Payment PPPs, this chapter provides details about developing a hybrid model that would design MAPs and concession term while protecting the public and private interests simultaneously. The hybrid model (linear) is developed by combining stochastic dynamic programming (SDP) and multi-objective linear programming (MOLP) models.

### 3.1 Nature of the Problem

Availability Payment PPPs are long-term PPPs that require the private sector to perform and keep the highways available throughout the concession period. Since these contracts are long-term contracts it would be better if a method could enable integrating the effects of dynamic changes occurring during the term of the project in the design process. In addition, it was desired that the model help the decision-makers for monitoring the project progress and also help to take decisions upon realization of unexpected results occurring due to the dynamic nature of the project. In addition, since these projects are long-term projects, there are risks associated with uncertain events occurring. Hence, stochastic dynamic programming (SDP) framework was selected to model these long-term PPPs.

Apart from this, the public and private sectors have competing objectives in PPPs. The private sector wants to earn as much as possible from the funds allocated for the project, while the public sector tries to minimize spending those funds to protect public interests. In addition, the public sector must attract the private sector by allowing them to earn at an appropriate internal rate of return (IRR). Hence, the PPPs must be designed to satisfy the competing objectives simultaneously, which necessitates that the model be developed as a multi-objective model. Therefore, the Availability Payment PPP model was developed as a multi-objective linear programming model (since all the equations that formed the constraints and objective function were linear).

Thus, the dynamic, probabilistic and multi-objective characteristics of Availability Payment PPPs necessitated that a hybrid model be developed. This led to the development of a hybrid model by blending the multi-objective linear programming principles with a stochastic dynamic programming model.

### 3.2 Developing Model for Availability Payment PPPs

The two most important features of the Availability Payment PPPs are MAP and concession term. Hence, a hybrid model was developed for designing MAP and concession term for these PPPs. In addition, the SDP framework within the hybrid model was inspired by the inventory model (also known as Economic Order Quantity (EOQ)

Inventory model) used in supply chain management. Gabriel et al., (2004) have used the inventory model formulation for determining optimal forward-load estimates for the electric power market. The authors designed the model by setting up electric power market parameters in the inventory model framework. The original inventory model is generally used to determine optimal production strategy, taking into consideration several parameters, namely, production costs (variable costs), fixed costs (fixed charge costs), inventory storage costs (variable costs), salvage costs (variable costs) and random demand (Winston, 2004). When the demand is random, the model must be set up considering random demand and such a model falls in the category of SDP models. The generalized form of the classic inventory model can be expressed schematically as shown below:

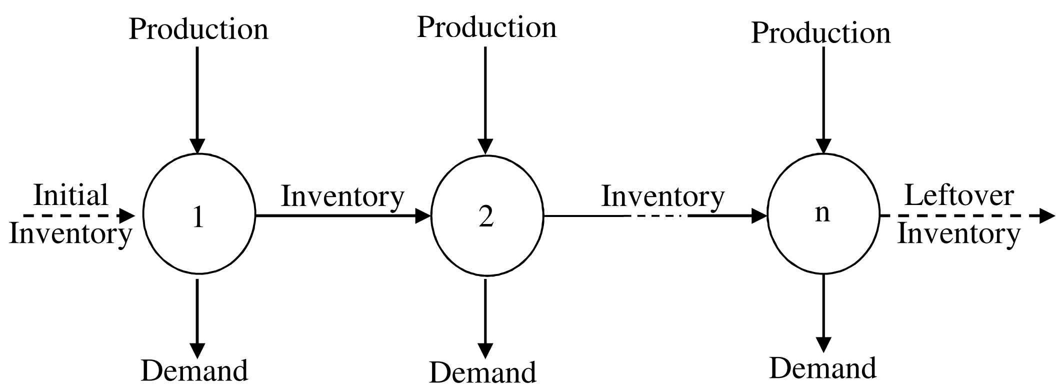


**Figure 3 Inventory Model From Supply Chain Management (Source: Gabriel, 2009)**

The classic inventory model is used to determine how much quantity should be produced at a manufacturing plant during each month (stage) when the demand is random. The model allows us to consider situations such as having initially stocked inventory and also the situations when the unsold items may be salvaged or trashed.

The inventory model displayed in Figure 3 is modified for PPP projects. The analogous inventory model representing PPPs is shown in Figure 4. The analogy between the two models is listed in Table 1 and is discussed briefly in the following part of this section.

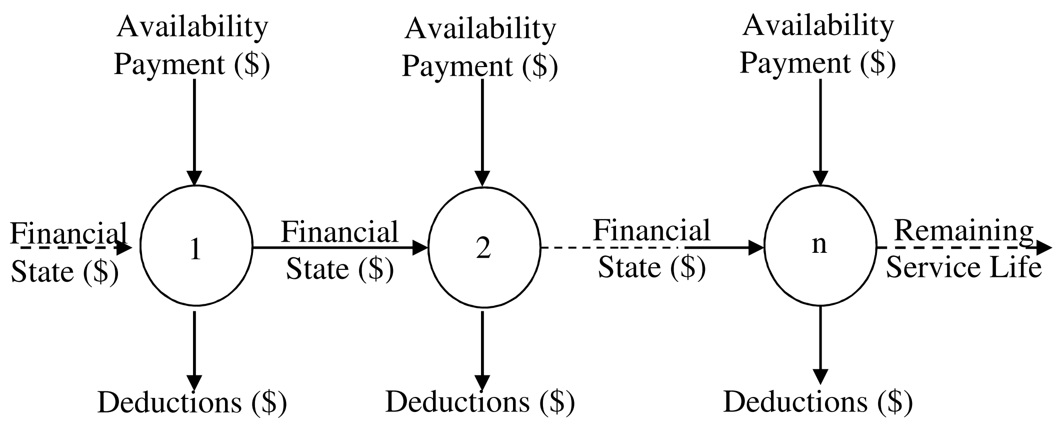


**Figure 4 Inventory Model Application to PPPs**

**Table 1 Analogy Between the Inventory Model and the Availability Payment Model**

| Mathematical Term | Inventory Model | PPPs with Availability Payment |
|---|---|---|
| Stage | Month | Years |
| State | Inventory | Financial state of the private sector (in $M) |
| Objective Function | Minimize Cost | Minimize Cost to DOTs and variation in private sector's financial state (in $M) |
| Decision Variable (Stage t) | Production Quantity | Maximum Availability Payment For a Given Concession Period (in $M) |
| Initial Realization (Stage t) | Initial Inventory | Private sector's financial state after construction phase (in $M) |
| Random Variable (Stage t) | Demand during a particular stage | Deductions for underperformance (in $M) |
| Intermediate Realization (Stage t+1) | Unsold Inventory at stage t+1 | Financial state of private sector$_{t+1}$ = Financial State Realized $_t$ + Availability Payment $_{t+1}$ – Realized Deductions $_{t+1}$ (in $M)) |
| Element (Last stage) | Left over inventory | Remaining Service Life (RSL) costs (in $M) |

### 3.2.1 Initial Financial Condition

In the inventory model, initial inventory influences the solution of the problem. If the initial inventory is high, the decision to produce in subsequent periods, derived by solving the model, might lead to a solution to produce less and vice versa. In PPPs with availability payment mechanisms, the private sector's financial state at the beginning of the concession term can influence the solution in a similar way. If the financial state is good, the decisions can be made to have lower MAPs and vice versa. The financial state, on the other hand, depends on how much private equity was allowed in the project and how much money was reimbursed to the private sector for its construction activities. Usually, the private sector will not be able to fully recover its investment at the beginning of the operation phase. This would mean that the private sector would be forced to perform during the operations phase to recover its investment and also earn the expected profit.

### 3.2.2 Deductions

In the classical inventory model, demand is a random variable and it influences the optimal decisions. The analogy of demand is deduction in the proposed model. The deductions applied to MAPs influence the overall reimbursement to the private sector and also the financial condition of the private sector. If the deductions are high, it can stress the financial condition of the private sector but, if the deductions are low, the public sector might be criticized for not considering low deductions while designing the PPP.

### 3.2.3 Financial State Realized

The classic inventory model calculates unsold stock after every stage. The unsold inventory becomes the initial inventory for the next stage. Using the same approach in the proposed model, the private sector's financial state after a particular year (i.e., stage) will become the initial state for the succeeding year. If the deductions are higher, the financial condition will be stressed (i.e., the financial condition will have lower values), which may threaten the existence of the PPP contract. Hence, in that case, the public sector may want to increase the amount of payment to the private sector. On the other hand, if the deductions are lower than expected, the private sector's financial state can reflect unexpected gains to the private sector, which indicates loss to the public.

### 3.2.4 Remaining Service Life and Maintenance Costs

In the inventory model, after going through all the stages, if something is unsold it must be scrapped off or sold out at a salvage value. Similarly, after the transfer of the asset to the public sector, the asset may have some service life left in the asset. For example, the concession period of a PPP is 30-years and the highway is transferred back to the public sector. The public sector now owns all the useful life of the structure (known as Remaining Service Life) along with its maintenance responsibilities. The maintenance responsibilities will incur costs. These costs are considered in this model just as the unsold inventory is considered in the classical model. These costs are called Remaining Service Life (RSL) costs. Including RSL costs in the model will allow us to consider the design life cycle of the project, which generally extends beyond the concession period.

### 3.2.5 Selecting State and Stages

In this model, the private sector's financial state is considered as the "state" of the model and years of operation are considered as "stages" of the model. Thus, a 30-year concession can be modeled to have 30 stages, and during each stage, the private sector takes some financial state. We can set up our model so that each year represents a stage. However, this will increase the computational burden significantly but will provide limited value to the decision-makers since the decisions cannot be made (rather, changed) yearly in PPP projects. Hence, it is appropriate to reduce the number of stages.

The stages can be reduced to a minimum of three stages (unless we do not want the model to have stages at all), where the first stage will represent the beginning of the ramp-up period of the operations phase, the second stage will represent the end of the ramp-up period and beginning of the operations phase, and the final stage will represent the end of the concession period. The ramp-up period is the initial 5 to 6 years of highway operations during which the highway experiences a rapid increase in traffic volume, but after this period the traffic volume increases at a very slow rate (Fitch, 2007). Hence, it is recommended here that the first stage should always be the beginning of the concession period and the second stage should always be considered after 5 or 6 years, which will enable the model to include the ramp-up period in computations. It must be noted here that in case of PPPs with availability payments, traffic volume will not affect the maximum availability payments, but by considering the second stage at the end of ramp-up period, it will help the model capture the private sector's initial performance, which can be used to project the private sector's performance for the rest of the concession term. The third stage will be the end of the concession period. The period between the end of ramp-up period and the end of the concession period can be divided by considering factors such as total years of concession period, investment amount, risk of failure of PPP and the time available for this analysis. Once the stages and states are fixed, the model can be used to conduct analysis on the financial aspects of the project. It must be noted here that since the model enables considering yearly (stage-wise) analysis of the project finances, real cash flows must be used in this analysis.

### 3.3 Model Formulation

The following part provides details to set up formulation for designing availability payment terms as well as establishing the relationship with the classical inventory model.

#### 3.3.1 Decision Variables

In case of classic inventory model, the decision-maker is supposed to decide how many units should be produced in order to minimize the costs. In the proposed PPP model, the DOTs have to decide what amount should be considered for annual payments and what should be the duration of concession. Hence, in the proposed model, we consider $MAP_P$ as the decision variable. The following illustration shows how to select $MAP_P$s for this model.

*Suppose that a DOT has a budget of $1Billion for the project. It invites bids from Private Parties disclosing the limit on MAPs. The disclosed limit of MAPs is the upper limit of money for the project. This allows the private sector to analyze the project and check whether an appropriate rate of return is attainable or not. If the project can offer a desirable rate of return, private party bids for the project. In this scenario the private party's financial status (derived by equity cash flow statement) considering100% of MAPs throughout the concession period represent the upper boundary of the money that* *could be earned from the project. On the other hand, the financial status considering the adjusted MAPs (i.e., reduced MAPs for contractual non-compliance) that would just satisfy the private party's internal rate of return defines the lower boundary of money. The difference between these two boundaries represents the amount of money that is beyond what the private sector expects. This leads us to conclude that an ideal MAP design would be the one that would reduce public sector costs, but at the same time satisfy the private sectors internal rate of return.*

*Hence, in this analysis we select several values of MAPs (decision variables) such that these would let the private sector earn higher than its IRR but less than the budget available for the Project. This requires that the MAPs for this analysis are selected between the full MAP and the adjusted MAP that would allow the private sector to earn at an acceptable rate of return. Hence, if the public sector expects that the largest MAP would be $100K and MAP of $94K would satisfy the private sector's IRR then the MAPs for our mode can be selected as shown in Table 2.*

**Table 2 *Example of Choices for Decision Variables in the Availability Payment Model***

| *Decision Variables* | $MAP_1$ | $MAP_2$ | $MAP_3$ | $MAP_4$ | $MAP_5$ | $MAP_6$ | $MAP_7$ |
|---|---|---|---|---|---|---|---|
| *Values (in $ 1000)* | *94* | *95* | *96* | *97* | *98* | *99* | *100* |

The above table is similar to the inventory model's decision variable, where the manufacturer has the option of manufacturing 0, 1, 2, 3, 4 or 5 units (since the lower limit is 0 and the upper limit is 5) and the decision-maker is required to make the decision on what quantity to produce during a particular period. Furthermore, the decision-maker may also want to vary the duration of concession. Hence, if the concession term is varied while keeping the overall payment fixed, a similar table can be easily constructed.

### 3.3.2 Objective Function

The classical inventory model minimizes total costs of inventory management. Similarly, the proposed PPP model minimizes the Life Cycle Costs (LCC) to the public sector. The Life Cycle (LC) considered in this model includes the concession period and all the years between the end of concession and the second major highway upgrade/rehabilitation. Considering the years between the end of concession and the second major upgrade in the lifecycle will ensure that the model captures all the major costs beyond the concession period.

Furthermore, this model has been designed as a multi-objective optimization model. In a multi-objective optimization model, several objectives (even conflicting and competing objectives) can be incorporated at the same time. In PPPs, the public sector and private sector play major roles in the overall success. Hence, decision models must consider the concerns of each party adequately, which justifies the use of a multi-objective optimization model for PPPs. By including private and public sector objectives, this model will capture the essence of PPPs, “sharing risks and rewards optimally.”

In the current research, the objective function is formed by combining public and private sector objectives in a single equation. Since the method of weights (as described in

Section 2.6.2) will be used during analysis, these parts of the objective function are applied by appropriate weights. The weighted multi-objective function can be represented as:

Objective Function = Minimize (Weighted Public Sector Costs + Weighted Variation of Private Sector's Financial Status)

$$MAP^P = \underset{MAP^P}{\arg min} \sum_{i=1}^{n} w_1 \left[ MAP_t^P - \sum_{i=1}^{m} D_t^i + RSL_t \right] + w_2 \cdot |CFS_t - FSA_t|$$

$$\text{where } RSL_t = \begin{cases} 0 & t < T \\ f_{RSL\ Costs} & t = T \end{cases} \qquad (3.1)$$

Where,

$MAP^P_t$ = Maximum Availability Payment at stage t

$D^i_t$ = Deduction during stage t corresponding to event i ~ probabilistic distribution

$CFS_t$ = Control Financial State at stage t

$FSA_t$ = Financial State Achievable at stage t

$w_1$ and $w_2$ are weights for the objectives

p = number of decision variables considered

m = number of events contributing to deductions

T = number of years of concession

In the above equation, public sector cost (represented by $MAP_t^P - \sum_t^m D_t^i + RSL_t$) is the amount paid by the public sector, after having deductions from MAPs for unavailability of highway. Notice that the $RSL_t$ represents the costs associated with Operations and Maintenance of the highway after concession period. Hence these costs will only be added once at the end concession term. Thus, the public sector costs have been represented as:

$$f'_{Public} = MAP_t^P - \sum_{i=1}^{m} D_t^i + \mathrm{RSL}_t \tag{3.2}$$

The second part of the objective function (multiplied by $w_2$) represents variation in private sector's financial status during stage t has been formulated as:

$f'_{\text{Private}}$ = Variation of Private Sector's Financial State

= |Control Financial State $_t$ – Financial State Achievable $_t$|

= |Control Financial State $_t$

– (Financial State Realized $_{t-1}$ + $MAP^1$ + $FA^s_t$ - $\sum_{i=1}^{m} D_t^i$)| (3.3)

Where, $MAP^1$= The biggest MAP possible

$FA^{s}_{t}$ = Financial Adjustment at stage t when public sector selects $MAP^{p}$

= $MAP^{4}_{t}$ - $MAP^{1}$ if public sector selects fourth MAP during stage t

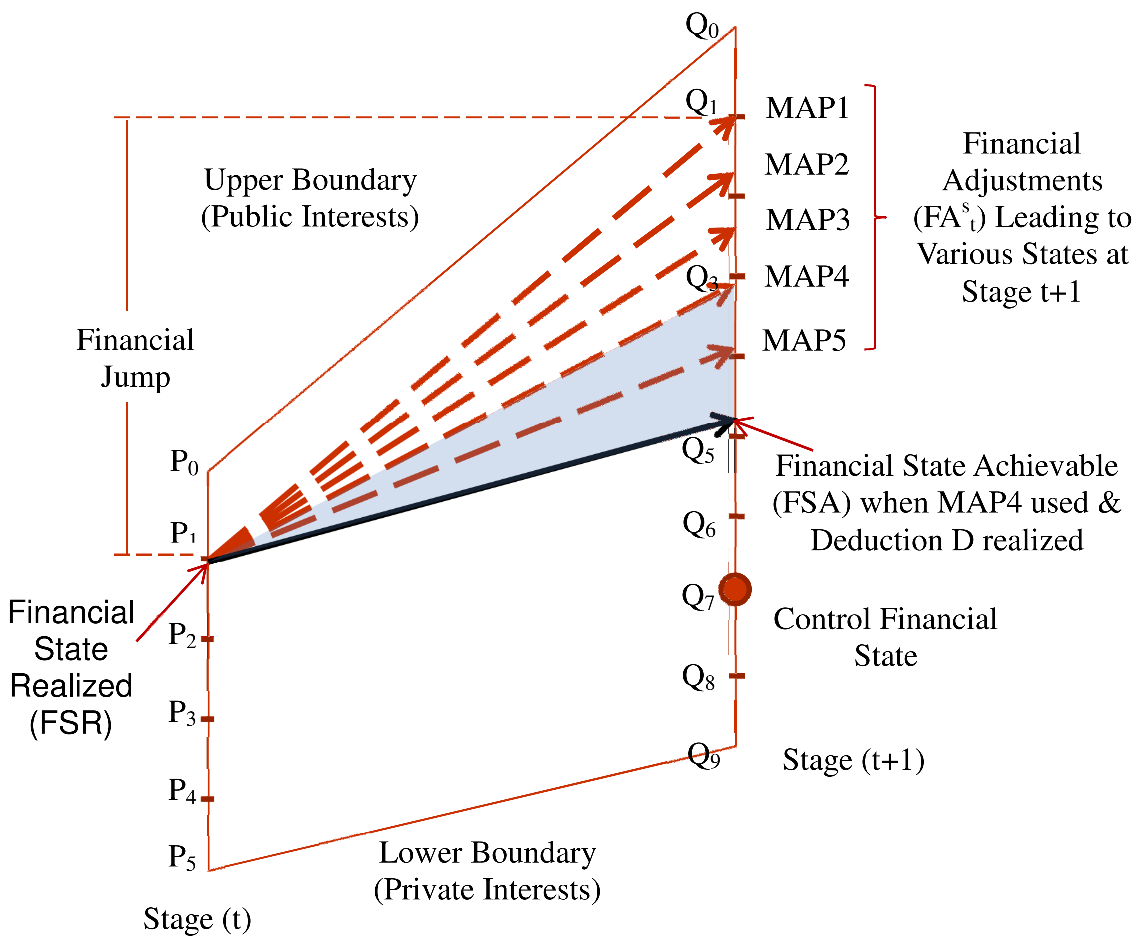


**Figure 5 Explanation of Terms Used in the Model**

Equation 3.3 can be better understood through a graphical representation. The above Figure 5 presents the logic behind using formulation and would help in understanding the MOSP model in a better way. In the figure, the inclined upper boundary represents the public interests and the model will not allow selection of MAPs that would enable the private sector finances to exceed this boundary. On the other hand, the inclined lower boundary represents the private interests and the model will not allow selection of MAPs that would reduce the private sector finances to drop below this boundary. The dotted arrows represent MAPs, the decision variables. Let us assume that at some stage t, the private sector assesses its financial condition and finds the project's financial condition represented by point $P_1$ (shown in the figure 5).

If the public sector selects the fourth MAP option (out of the total 5 options available) between stage t and stage t+1, it would reach a point represented by $Q_3$. This point corresponds to situation where the private sector pays all its expenses and earns 100% of MAP. This financial condition can be calculated algebraically by adding income (considering the fourth MAP option) and contractual expenses between stage t and stage t+1. However due to uncertainty, the private sector might not reach the point $Q_3$ but might reach a point $Q_5$ due to the deductions (the shaded area is used to show deduction). To calculate the financial condition represented by point $Q_5$, we must perform the following operation:

$$\text{Financial State Achievable} = FSR_{t-1} + MAP^{1} + FA^{s}{}_{t} - \sum_{i=1}^{m} D_t^i \qquad (3.4)$$

Where,

$FSR_{t-1}$ = Financial State Realized at stage (t-1)

In addition to this, depending on the MAP selected and the deductions faced, the private sector would achieve the financial state represented by $FSA_{t-1}$. However it is desired that the private sector meets the status represented by $CFS_t$. The difference between $FSA_t$ and $CFS_t$ represents the variation in the private sector's financial condition. Furthermore, since the optimization operator for the model is a minimization function, we must always have a positive value of $CFS_{t-1} - FSA_{t-1}$ so that the difference can be minimized. This was achieved by taking absolute values of the difference.

Putting all the equations together and considering weights for the two objectives as $w_1$ and $w_2$, we get the objective function for the problem as expressed in equation 3.1.

### 3.3.3 Constraints

The following section introduces the constraints that affect the overall project execution and results.

#### 3.3.3.1 Limits on the Private Sector's Financial State

Under ideal conditions, the private sector will meet the contractual performance regarding availability of highway lanes. This would enable them to get MAPs reimbursed without any deductions and allow them to earn the maximum possible amounts. This represents the upper limit of the private sector's financial condition at a given stage (represented by the upper inclined boundary in Figure 5). However, this state cannot be achieved and the MAPs will be reduced due to deductions. At any given stage (year), the private sector will continue operating and maintaining the asset if and only if the private sector is able to earn at a minimum acceptable rate of return. The boundary formed by considering all the financial states below in which the private sector would quit the partnership represents the lower limit of acceptable financial state and can be calculated by assuming a minimum rate of return for the private sector. In Figure 5, this has been represented by the lower inclined boundary. Mathematically, this can be represented below:

$$f_{\text{Financial State}} \leq \text{ULP} \tag{3.5}$$

$$f_{\text{Financial State}} \geq \text{LLP} \tag{3.6}$$

Where,

$f_{\textit{Financial State}}$ = Financial condition of a private party and is derived by accruing annual equity cash flow developed by including the actual money reimbursed (i.e., MAPs – Random Deductions) to the private sector

ULP = Upper Limit of Payment and can be obtained by accruing annual equity cash flow developed by including MAPs only (i.e., no deductions applied)

LLP = Lower Limit of Payment and can be obtained by accruing annual equity cash flow developed by including the reimbursements to the private sector with maximum allowable deductions that would satisfy their minimum acceptable rate of return (MARR).

#### 3.3.3.2 Remaining Service Life Cost

The Availability Payment PPPs are generally 20-40 years duration. During these 20-40 years of concession, the concessionaire maintains the highway, but after the concession period, the maintenance responsibility is handed over to the public sector. The public sector would be required to maintain the highway for the remaining service life of the highway. The RSL maintenance costs will vary with the variation of concession term since if the concession period is smaller, and the remaining life cycle costs will be higher and vice versa. This happens since the increase or decrease of the concession period by some years will correspondingly reduce or increase the RSL maintenance costs.

Hence, we can say that depending on the availability payment options considered for analysis (i.e., MAP and duration of concession), there will be a corresponding RSL maintenance costs. The DOTs are known to use well-established guidelines to plan maintenance as well as estimate costs for highways (Caltrans, 2007) as well as reports such as NCHRP 688 also have guidelines to estimate highway maintenance costs. Using these guidelines and depending on the concession period, the RSL maintenance costs can be estimated, which can vary with the concession terms between some upper and lower limits. These can be expressed as:

$$f_{\text{RSL cost}} \leq \text{MaxEMC}_{T} \tag{3.7}$$

$$f_{\text{RSL cost}} \geq \text{MinEMC}_T \tag{3.8}$$

where,

$f_{\text{RSL cost}}$ represents highway's estimated remaining service life costs (RLS Cost) implemented via a lookup table developed by using procedures established by guidelines/reports/manuals such as Determining Highway Maintenance Costs (NCHRP 688) or the procedures adopted by various State DOTs for maintenance and rehabilitation of highway networks.

$\text{MinEMC}_T$ = Minimum Expected Post-Concession Maintenance Cost corresponding to T concession years

$\text{MaxEMC}_T$ = Maximum Expected Post-Concession Maintenance Cost corresponding to T concession years

### 3.3.4 Recursion Formula

Winston (2004) described the processes of developing recursion formulae. If the objective function is to minimize costs, the recursion function can be expressed as:

$$f_t(FSR)$$

$$= \underset{MAP^P}{min.} \left\{ (expected\ value\ of\ Objective\ Function\ at\ stage\ \ t | FSR, MAP^P) + \sum_{FSA \in \Omega} p(FSA|FSR, MAP^P, t) f_{t+1}(FSA) \right\} \quad (3.9)$$

where,

$f_t(FSR)$ = minimum value of expected public and private sector objectives that can be calculated for stage t by considering stages $t$, $t + 1$, … end of the problem given that the state at the beginning of stage $t$ is *FSR*.

$p(FSA|FSR,MAP^P,t)$ = probability that the next period's state will be FSA, given that the current (stage t) state is *FSR* and action $MAP^P$ is chosen = $p_{FSA@\ t+1}$

$\Omega$ = set representing possible values of FSA

This can be further simplified by appropriately substituting the values in the previous equations and a simplified version as shown below can be obtained:

$$f_t(FSR) = \underset{MAP_P}{min.} \Bigg[ (Expected\ MOF | FSR_t, MAP^P) + \sum_{FSA \in \Omega} p_{FSA@\ t+1} \left\{ \sum_{t'=t+1}^{T} w_1 \left( MAP_{t'}^P - \sum_{i=1}^{m} D_{t'}^i + RSL_{t'} \right) \right\} + w_2 |CFS_{t'} - FSA_{t'}| \Bigg]$$

(3.10)

Where,

(Expected MOF|FSR, $MAP^P$) represents the expected value of multi-objective function (MOF) at stage t given that the current (stage t) state is *FSR* and action $MAP^P$ is chosen

$p_{FSA@\ t+1} = p(FSA|FSR, MAP^P, t)$

### 3.4 Comprehensive Model

By putting the equations, 3.01 to 3.10 together, we get the final model as shown below.

$$MAP^P = \underset{MAP^P}{\arg min} \sum_{t=1}^{T} \left\{ w_1 \cdot \left( MAP_t^P - \sum_{i=1}^{m} D_t^i + RSL_t \right) \right\} + w_2 \cdot |CFS_t - FSA_t|$$

$$\text{where } RSL_t = \begin{cases} 0 & t < T \\ f_{RSL\ Costs} & t = T \end{cases}$$

$$f_{\text{Financial State}} \leq \text{ULP}$$

$$f_{\text{Financial State}} \geq \text{LLP}$$

$$f_{\text{RSL cost}} \leq \text{MaxEMC}_T$$

$$f_{\text{RSL cost}} \geq \text{MinEMC}_T$$

$$f_t(FSR) = \underset{MAP_P}{min.} \left[ (Expected\ MOF | FSR_t, MAP^P) + \sum_{FSA \in \Omega} p_{FSA@\ t+1} \left\{ \sum_{t'=t+1}^{T} w_1 \left( MAP_{t'}^P - \sum_{i=1}^{m} D_{t'}^i + RSL_{t'} \right) \right\} + w_2 |CFS_{t'} - FSA_{t'}| \right]$$

3.11

**3.5 Alternate Forms of the Model**

The model (3.11) represents the hybrid model, which can be used to design the MAPs, and concession term for Availability Payment PPPs. Depending on the availability of information, the model can be modified for analysis purposes. The model can be modified when the following occurs:

1. When Information is Available

   When all the necessary information is available, the model (3.11) can be changed and used as a deterministic model (Appendix 2). Notice that if expected values are used in the model (Appendix 2) the analysis will be considered as a deterministic analysis. In this report the model using expected values will be called Multiobjective Deterministic Dynamic Programming Model (MODDP)

2. When Probabilities Can Be Calculated or Predicted

   When the probabilities associated with random variables can be calculated we can use the model (3.11) directly. Such a model will be called Multiobjective Stochastic Dynamic Programming (MOSDP) model.

3. When probabilities cannot be calculated or when effect of combination of extreme values deductions is desired

   Sometimes the probabilities cannot be calculated or we might be interested to see the effect of various combinations of random values on the results. In such conditions we can use simulations (model in Appendix 3). The model basically replaces the deductions with simulated values of deductions. Such a model is called Multiobjective Simulated Dynamic Programming (MO$\tilde{S}$DP) model in this research work.

In addition to these variations, the models can be further extended to include more objectives. This could allow the model to simultaneously satisfy several objectives of both the sectors. Last, the Control Financial State (CFS) used in the model can be linked with several screening and performance criteria including, but not limited to, concessionaire's experience, financial stability, market reputation, safety, lane availability, highway through put and passenger comfort. Hence, if the concessionaire is expected to do poorly on these criteria, the CFS can be designed and used to reflect such a concessionaire in the model. This would enable the decision-makers to set up the model specifically to a concessionaire and use it to determine the negotiable MAP and concession terms.

### 3.6 Using the Model

The MOSDP model (3.11) presented in Section 3.4 is developed considering a SDP framework. Hence, the analysis requires using backward-pass calculations wherein the analysis begins from the last stage and continues stepwise to reach the start of the problem. The method of using the backward-pass has been summarized in the following seven steps (adopted from Winston, 2004):

1. *"The problem must be broken into several stages."* Collectively, all these stages form a mechanism by which the problem can be built up. In our MOSDP model concession term is broken into several stages, each stage representing several years. When put together, the stages would represent the concession term. This can be better explained using Figure 5 and Figure 6 together. Figure 5 shows two stages: stage (t) and stage (t+1). By combining all the stages we obtain the concession term shown in Figure 6.

2. *"The state at any stage gives the information needed to make the correct decision at the current stage."* In our model the Financial State Realized ($FSR_t$) represents a state during stage t. This can be visualized using Figure 5 where states during stage t are represented by points $P_0$, $P_1$, … $P_5$ and states during stage t+1 are represented by points $Q_0$, $Q_1$, … $Q_9$.

3. *"In most cases, we must determine how the cost incurred during the current stage (t) depends on the stage t decision, the stage t state, and the value of t."* In our model, current stage is represented by t, decisions by MAP and state at stage t by $FSR_t$. Using the objective function $w_1 \cdot \left(MAP_t^P - \sum_{i=1}^{m} D_t^i + RSL_t\right) + w_2 |CFS_t - (FSR_{t-1} + MAP_t + FA_t^s - \sum_{i=1}^{m} D_t^i)_t|$ allows us to achieve this objective. (Note that the formula used here is obtained by substituting the value of $FSR_t$ from equation 3.4 to equation 3.1)

4. *"We must also determine how the stage t +1 state depends on the stage t decision, the stage t state, and the value of t."* This was achieved by using the recursion formula (3.10). This recursion formula would allow us to determine the future stage decisions (i.e., selecting MAPs) considering future decisions (MAP), future stage's state (i.e., $FSR_t$) and the stage t itself.

5. *If we define $f_t(i)$ as the minimum cost incurred during stages t, t-1,..., T, given that the stage t state is i, then (in many cases) we may write $f_t(i)$ = min {(cost during stage $_t$) +$f_{t+1}$(new state at stage $_{t+1}$)}, where the minimum is over all decisions allowable in state i during stage t.* A very similar methodology was adopted here. The recursion formulae are discussed in Section 3.3.4. The stepwise development

shows that similar methodology is adopted during this research. Figure 8 has been developed with the aim to explain this process.

6. *We begin by determining all the $f_T$ (·)'s, then all the $f_{T-1}$(·)'s, and finally f1 (the initial state).* This approach will be demonstrated during the case study analysis in Chapter 4. However, the backward-pass has been explained graphically using the Figure 5 as well as Figures 6 to 10.

7. *We then determine the optimal stage 1 decision. This leads us to a stage 2 state, at which we determine the optimal stage 2 decision. We continue in this fashion until the optimal stage T decision is found*. This approach will be demonstrated during the case study analysis in Chapter 4. Furthermore these calculations will be referred as Realization Pass (or can also be referred as Forward Pass) in this research work because we move forward with the realization and using the solutions obtained during step 6. The realization pass has also been explained graphically using Figures 11 to 13.

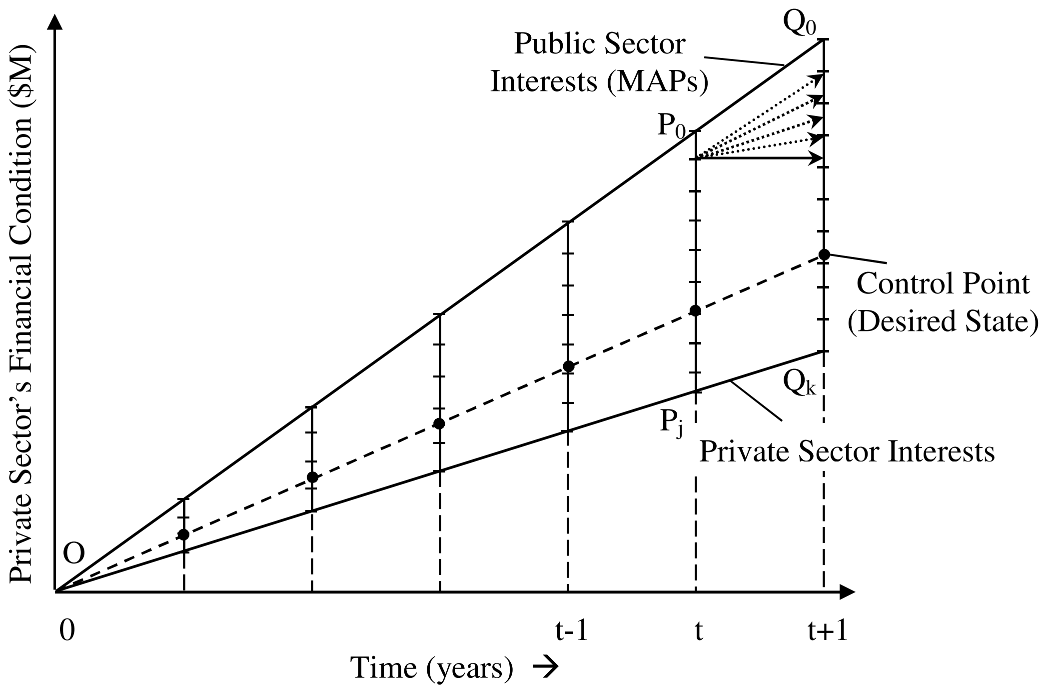


**Figure 6 Stages and States for a Concession Period**

Figure 6 is developed here to explain steps 1 and 2. Notice that in Figure 6 the line $OP_0Q_0$ represents the public sector interests, $OP_jQ_k$ represents the private sector interests, the Y axis represents private sector's financial condition, the X axis represents the concession term and is divided in stages 0, 1,…. t-1, t, t+1. The financial condition between lines $OP_0Q_0$ and $OP_jQ_k$ represents the states. Hence, at stage t the acceptable states can be represented by $P_0$, $P_1$…. $P_j$ where (j+1) is the number of states that are expected during stage t. Also notice, that when we focus on just two consecutive stages, we are concentrating on the area $P_0Q_0P_jQ_k$. The Figure 5 used in the previous sections was just focusing on a similar area.

Steps 3 and 4 can be explained using Figure 5. It can be observed that if a decision is taken to execute the fourth MAP during stage t, we might find the project to reach any value between $Q_3$ and $Q_5$. Also notice that, since the fourth MAP option was used during stage t, the decisions for stages t+2, t+3would only be based on the states between $Q_3$ to $Q_5$ during stage t+1. Figure 8 is developed to explain step 5, but before we discuss Figure 8, it is necessary to discuss what happens between stages when the MOSDP is run. Figure 7 is developed to show that the model would select the optimal answers.

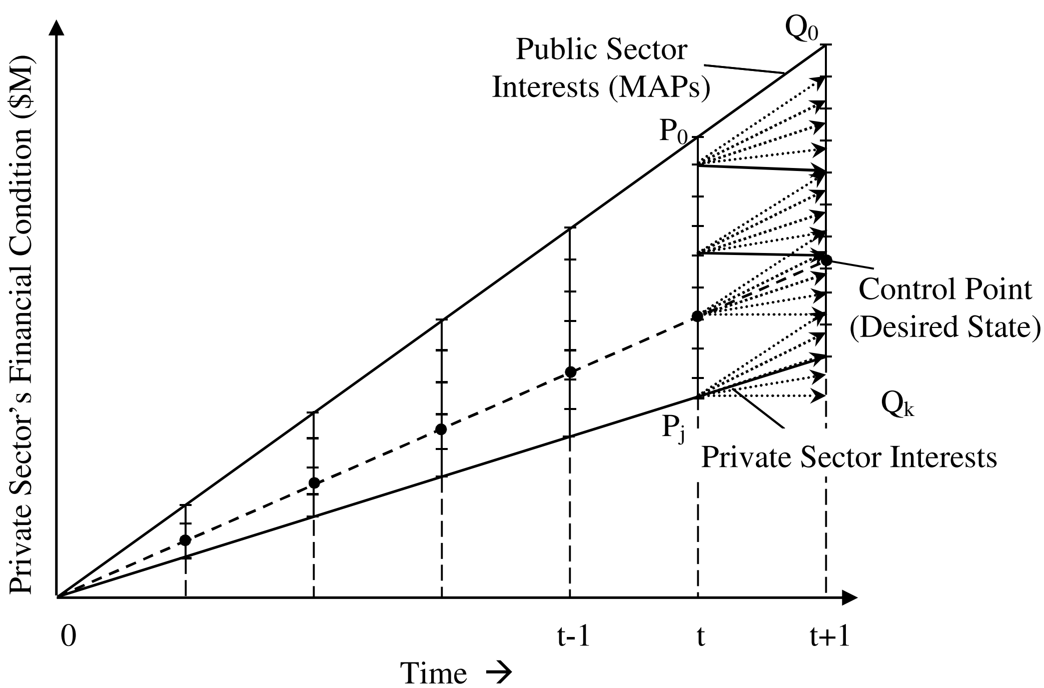


**Figure 7 Mechanics Behind the Model's Two Stages**

Consider that at stage t the $FSR_t$ (state), represented by $P_1$, is realized. From the current stage t and state $P_1$, the public sector must take a decision and adopt a MAP so that the public sector objective of reducing costs and private sector's objective of reducing financial variation can be achieved simultaneously. If the public sector decides to offer $MAP_1$ (the MAP having highest value) between stages t and t+1, the private sector's financial condition will be point $Q_1$. However, if the public sector decides to offer $MAP_5$ (the MAP with lowest value), then the private sector's financial condition during stage t+1 will be $Q_4$. In this scenario, if $MAP_5$ is offered, the public sector would be able to save money and variation of the private sector's financial status would also be less. Hence, the model would select the $MAP_5$ option. Notice that this is shown by a full line arrow in the figure. Similar will be the case when the $FSR_t$ will be $P_4$. However, when the $FSR_t$ is $P_6$ (which indicates that the private sector's financial status is low) selecting the MAPs offering lowest amount of money (i.e., $MAP_5$) would allow reducing public sector expenses but would increase private sector's financial variation. Hence, in such a scenario, the model would appropriately select the MAP option that would simultaneously reduce public sector expenses and variation of private sector's financial status. Last, if we consider $FSR_t$ to be $P_j$ (the state that implies just achieving private sector interests, i.e., just satisfying private sector's MARR), offering $MAP_4$ and $MAP_5$ would force the private sector to quit the project, since it can be seen that at stage t+1 that the FSR would be below the state represented by point $Q_k$. In such a scenario, the model would identify the solution only from the three feasible options $MAP_1$, $MAP_2$ and $MAP_3$. Continuing in this way, we can identify MAPs for all the possible $FSR_t$s and thus complete all the calculations for the stage t.

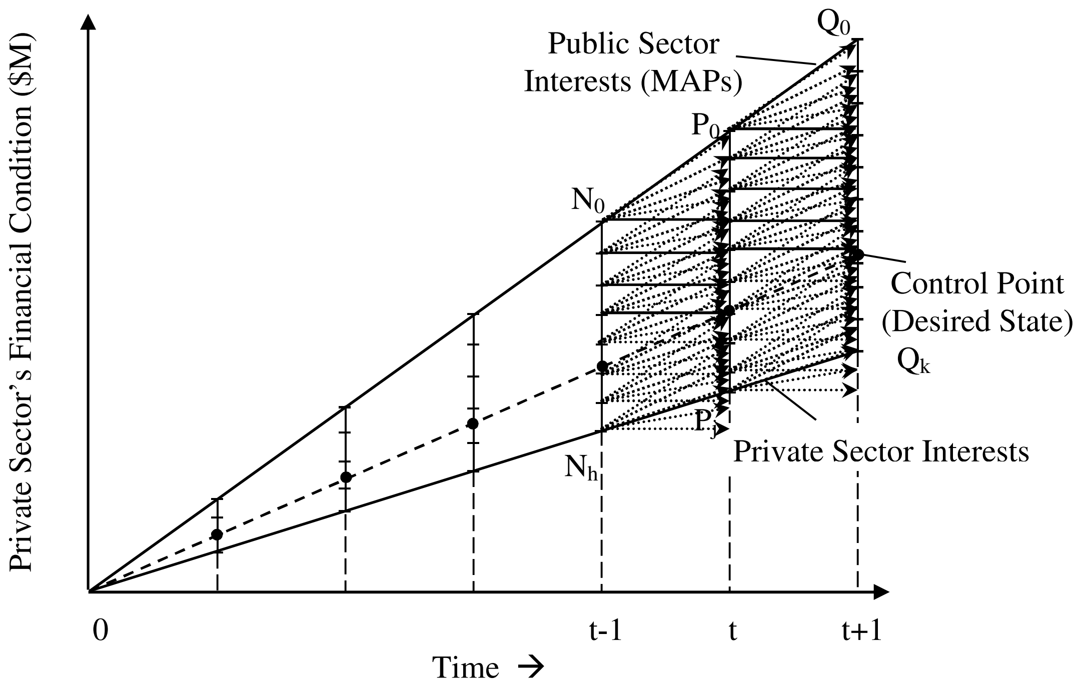


**Figure 8 MOSDP Model Connecting Two Stages**

Similarly, the calculations can be done for stage t-1 by moving one stage behind. Note that when we calculate the costs associated with decisions taken during stage t-1, we already have the costs that are expected to occur after stage t. This matches with the description of step 5, where the we carry out the operation represented by $f_t(i) = min \{(cost\ during\ stage_{t}) + f_{t+1}(new\ state\ at\ stage_{t+1})\}$. Figure 8 also explains what happens when we start executing step 6. Upon carrying out the step 6 fully, we get a complete solution to the problem. Graphically, this can be expressed by Figure 9.

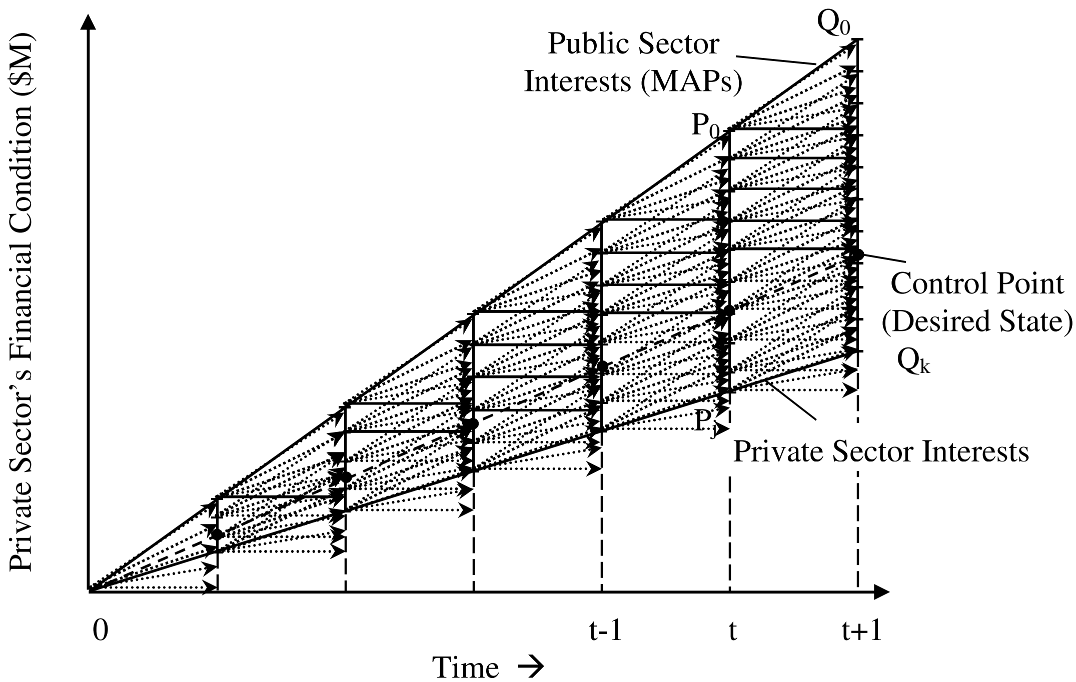


**Figure 9 MOSDP Model Run Fully Completing One Backward Propagation**

The solution can now be used to identify the MAP that would satisfy public and private sector objectives simultaneously. This leads us to step 7 of this procedure. This has been explained by Figures 10 through 12.

After obtaining the solutions for the whole concession term (Figure 9) the public sector uses the solution to identify the optimal solution and offers $MAP_2$ to the private sector (notice that offering $MAP_4$ and $MAP_5$, the lowest MAPs, would force the private sector to quit). The public sector offers $MAP_2$ to the private sector at stage 0 (represented by the bold black arrow) and waits untill stage 1 is reached. During this time, the private sector performs and the public sector realizes happenings between stage 0 and stage 1 (represented by shaded area in Figure 10). The public sector observes that the private sector has performed well (represented by the red bold arrow)

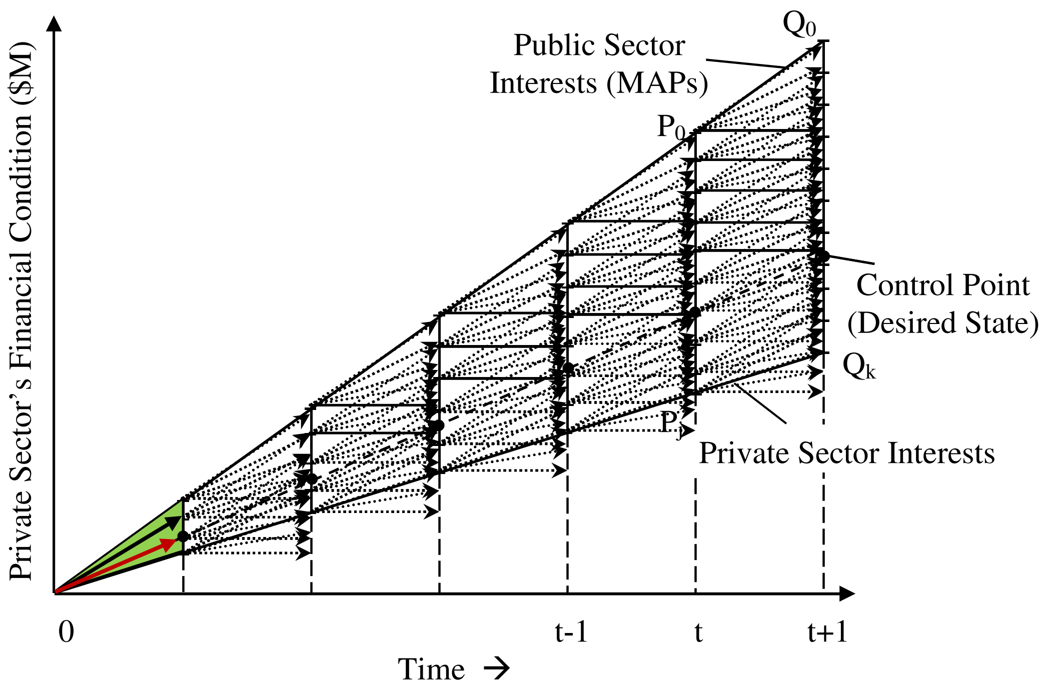


**Figure 10 Realization Pass Upon Realization During First Stage**

At stage 1, the public sector observes the FSR, and according to the optimal solution, offers $MAP_3$ to the private sector. As stage 2 is reached, the private sector's $FSR_2$ is realized (Figure 11). The $FSR_2$ represents that between stage 1 and stage 2, the private sector performs badly and the private sector's finds itself in a worst possible financial condition (since the $FSR_2$ hits the lower boundary).

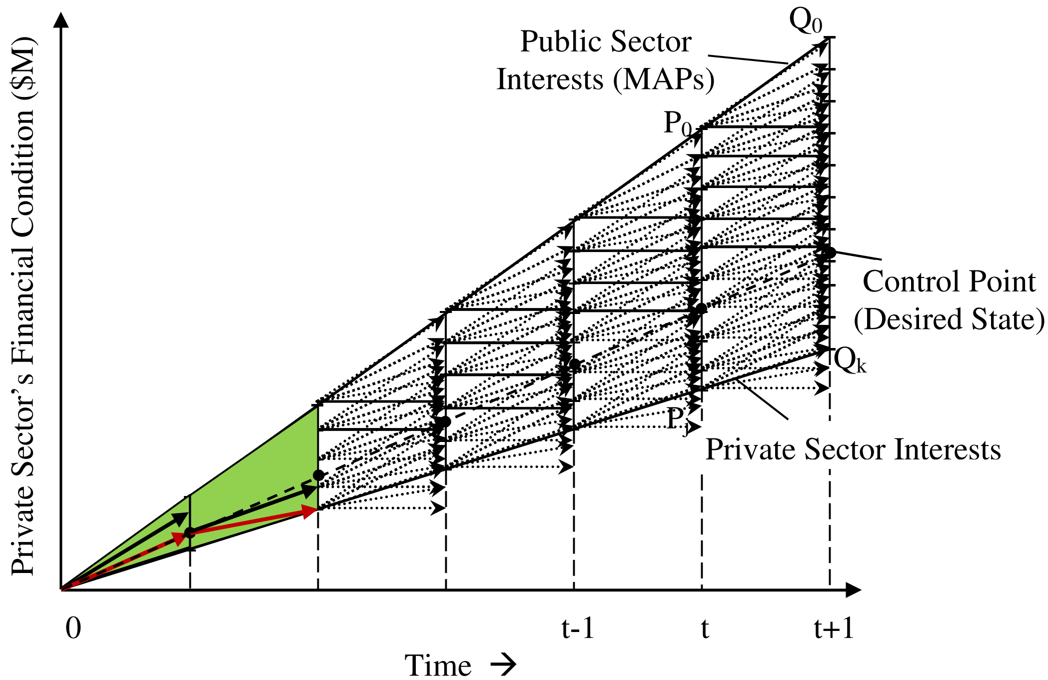


**Figure 11 Realization Pass Showing Realization Up To Second Stage**

In such a condition, the model might pick up MAPs with higher values to allow the private sector to recover and keep them motivated to be a part of the partnership. As done before, the public sector can again refer to the solution and offer the MAP that would satisfy public and private objectives simultaneously. Continuing stage by stage in the same way, the public sector can use the results to simultaneously minimize public sector costs as well as reduce the private sector's financial variation. Once the final stage is reached, the decisions and occurrences might look as shown in Figure 12.

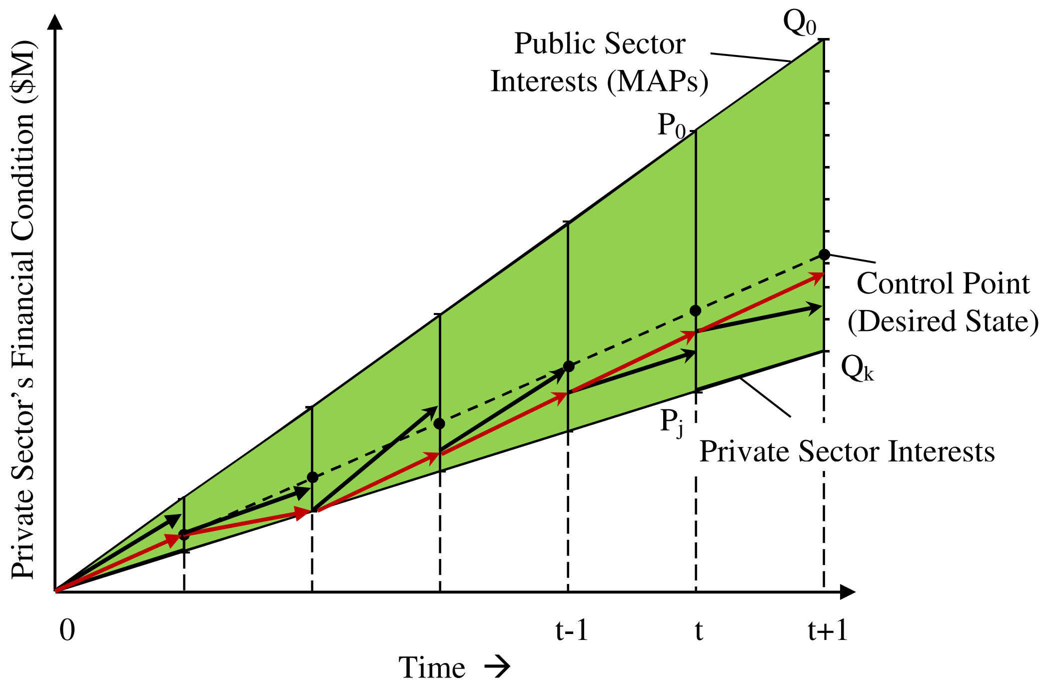


**Figure 12 Realization Pass Complete**

Notice that as the model allows taking decisions at various stages and at each stage the decision depends on the realized state, the use of such a model would ensure that the public sector costs are reduced, and the private sector ends up with a decent return.

Once all the results are available, the results can be analyzed using the concept of Pareto Optimality described in the previous chapter. The procedure explained in this section remains same for the MODDP, MOSDP and the MO$\tilde{S}$DP models.

## Chapter 4 Availability Payment Design of Presidio Parkway Project

This chapter provides a detailed case study demonstrating the use of the method described in Chapter 3. Caltrans' Presidio Parkway Project was selected for this research work and this chapter designs MAPs for this project. Analysis was carried out using two approaches: 1) using expected values, and 2) using random values during the backward-pass. The solutions obtained from both the approaches were then used and the model performance was observed simulating the private sector's performance. The "intelligence" gathered from the model performance was used to further improve the results. This step is referred to as the realization pass in this dissertation and is described in the previous chapter. The analysis was carried out considering discrete uniform distribution and triangular distribution.

### 4.1 Project Background

Presidio Parkway, also known as the Doyle Drive Replacement Project, is a $928.8 M PPP project currently in the construction phase in the State of California. This project will replace an existing 73-year-old south access to the Golden Gate Bridge. The originally built structure currently serves 120,000 trips per day, but has been declared structurally deficient, vulnerable to earthquakes and is at the end of its design life. The project has been divided into two different phases. The first phase consists of four contracts that focus on restoring the structure to meet seismic safety standards as well as developing new structures and temporary detour roads for keeping the existing roadways open. The next phase consists of four contracts and would ensure that the traffic is back on the permanently replaced facility (Caltrans, 2010).

The second phase of project was considered for delivery through different procurement options. The project consultants Arup/Parsons Brinkenhoff Joint Venture considered Design-Bid-Build (DBB), Design-Build-Finance (DBF) and Design-Build-Finance-Operate-Maintain (DBFOM) options for delivering the project. Their analysis showed that using the DBFOM option was better than using traditional DBB and the DBF options (Caltrans, 2010) because it:

1. offered better Value for Money (VfM) over the life of the project,
2. enabled optimal risk transfer,
3. offered greater certainty of cost and schedule at and after financial close,
4. promised the best use of public funds, and
5. ensured optimal level of Operations and Maintenance (O&M) service.

The analysis report shows that by using the DBFOM option, the Caltrans' project costs would be reduced by at least 20%.

On the basis of above information, the Presidio Parkway Project was decided to be procured as a DBFOM project with a concession period of 33-years (3years' construction and 30-years to operate and maintain). The public sector invited bids for the project and limited the MAmulti-objectivePs to $35.53M. The amount consists of MAP for design ($30M) and MAP for O&M costs ($5.53M). At that time, it would have helped the public sector to offer MAP limit to a level that would have helped the public sector to save money as well as ensure that the private sector bid for the project and remain in the project until the end. Hence, the MOSDP model was used to design the limit on MAP during the bidding phase.

During the bidding, it was observed that the private sector submitted bids with various financial plans and various construction costs. The reduction of construction costs and the financial plans contributed towards reduced project costs. The bidding helped in identifying the bidder offering the best value. On December 31, 2010, a DBFOM project agreement was signed between Caltrans and Gold Link Partners (the concessionaire (project company) formed by Hochtief, Meridiam, Flatiron, Kiewit and HNTB) (Saage & Ajise, 2010). By virtue of this agreement the Gold Link Partners (GLP) are now required to design, build and finance the project as well as operate and maintain the asset up to 2043. Upon meeting the performance standards (that includes availability of highway), the Caltrans would pay GLP availability payments.

Comparison of the business case submitted by consultant Arup/Parsons Brinkenhoff Joint Venture and the DBFOM agreement shows that the concessionaire would be able to perform construction activity for $254.03M and including other expenses (such as Special Purpose Vehicle Costs, O&M costs during construction, development costs, interests during construction and financing fees), the GLP would be responsible for paying $339.15M (source: Presidio Parkway Financial Proposal, 2010). This amount is much smaller than the construction cost of $477M estimated by consultant in February

2010. This resulted in GLP offering concessionaire services at MAPs of $28.5M, which is much lesser than the limiting MAP of $35.53M. The project document revealed that GLP could achieve such a big difference in MAPs by its unique financial plan. In addition, it is also assumed here that the concessionaire would be able to reduce the construction costs by $137.85M ($477M-$339.15M), since it expects to perform efficiently or it is just taking risks or it has precise information about the project conditions leading to reduced project uncertainty or the project scope getting reduced.

The reduction of MAPs and the overall costs are very encouraging and any public sector would willingly accept such a bid proposal. However, the public sector must not forget that even at the reduced project costs the private sector is expecting good returns from the project. Hence, the public sector must evaluate the bids and estimate the rate of return expected by bidders. This kind of evaluation might show that: a) the private sector being extremely efficient would be able to reduce the overall project costs and is expecting a reasonable rate of return, b) the private sector, being extremely efficient, would be able to reduce the overall project costs and is expecting high rate of return, c) the private sector is taking unnecessary risks just to win bidding, and d) the private sector is over optimistic about the project success. In addition to these scenarios, the private sector might be new to long-term projects or might be unaware of the conditions in the region. All these conditions could lead public loss since these conditions could yield too much profit to the private sector or increase the risk of the private sector's withdrawal from the project. Therefore, it is very important for the public sector to evaluate the bids, considering uncertainties that could affect the project success. In addition, the public sector must also be able to design MAPs and a concession term that could be used during negotiations. Hence, the MOSDP model would be used again to identify the negotiation terms. The MAPs and concession term designed using bids will be represented by MAP' and Concession Term'. The results from these designs will also be helpful for validating the MOSDP model.

## 4.2 Model Initialization and Assumptions

The MOSDP model discussed in the previous chapter must be set up to the pre-award condition for analysis. Following part of this section presents the process used to set up the MOSDP model for the case study.

### 4.2.1 Objective Function

The objective function for this research can be expressed as (as discussed in detail in Section 3.3.2, equation 3.1)

$$MAP^P = \underset{MAP^P}{\arg min} \sum_{t=1}^{T} \{w_1 \cdot [(MAP_t^P - \sum_{i=1}^{m} D_t^i) + RSL_t]\} + w_2 \cdot |CFS_t - FSA_t|$$

$$\text{where } RSL_t = \begin{cases} 0 & t < T \\ f_{RSL\ Costs} & t = T \end{cases}$$

The objective function requires values of MAP, deductions, control financial state, financial state achievable and weights.

#### 4.2.1.1 Selecting MAPs – Decision Variable

The MAP term in the objective function is a decision variable and we wish to determine the optimal value of the MAP that would minimize public sector costs as well as minimize variation in private sector's financial condition. Hence, we can define a range of values (continuous) between the highest and the lowest possible MAPs and then calculate the optimal MAP (Eschenbach et al., 1995 and Srinivasan, 2007). But, wanting the model to identify optimal MAP from a continuous range can pose the following issues:

Curse of Dimensionality: Stochastic Dynamic Programming (SDP) models are cursed for dimensionality (Gabriel et al., 2004). When SDPs with continuous values are used, the computational challenge can increase exponentially (See Appendix 13). This may require computers with very high computation capacity as well as much longer times to solve the problem. However, the problem at hand does not require a very high computational accuracy (reasons explained in ii) below); hence, if the SDPs are used with discrete values of MAPs, the computational burden can be reduced significantly and the problem can be solved using a routine personal computer (Windows 7, Intel i3 processor).

Rounding-up the Values – A Common Practice in Construction

Values are always rounded to the nearest 10s, 100s, 1,000s, millions or billions in the construction industry. For example, when a construction cost estimate is prepared, the values are rounded up: a cost of $1,580,329.07 will be rounded up as $1.6M or $1.58M.

Since the numbers are rounded up during the project, it would provide limited value to the overall results. Hence, this case study formulates the MOSDP with just five MAP values. In addition the financial states ($FSR_t$, $FSA_t$ and $CFS_t$) will be rounded up to the nearest integer values.

The Presidio Parkway Project document shows that the project would have 33-years of concession. These 33 years includes 3 years of construction and 30 years of O&M. The inclusion of 3 years of construction in concession term is different from the general definition of concession adopted by FHWA's Innovate Program Delivery and hence in this research designing the concession term would mean that designing the O&M concession only. During the 30-years of O&M concessions the concessionaire would be eligible for receiving $30M for design (constant throughout the term) and $5.53M for O&M (adjusted for inflation). When adding up this amount, the availability payment for the first year adds up to $35.53M and, after 30-years of operations, this amount increases to $40.48M (approximately). The Appendix H of Presidio Parkway Business Case provides the payment plan to the private sector. These payments are shown in the Appendix 4.

For the purpose of analysis, we also use the values of $33.93M, $34.33M, $34.73M, $35.13M and $35.53M as MAPs in this model. The lowest value of $33.93 is selected here since the annual deduction (calculated in the next step) is $1.66M for satisfying private sector's expected minimum acceptable rate of return (MARR). The other values of MAPs (viz. $34.33M, $34.73M and $35.13M) are selected as per the discussion in

Section 3.3.1. It is expected that the model would be able to select one MAP (dominant MAP) that minimizes the overall cost to the public sector as well as reduces the overall variation of private sector's finances.

#### 4.2.1.2 Deductions

As described earlier (Section 3.2.2), the deductions are random. These deductions occur due to factors such as crashes, breakdowns, regular maintenance, periodic maintenance, weather and any other factor that can result in the non-availability of highway lanes. The Presidio Parkway contract enlists all such activities and factors that can be contributed towards unavailability of highway lanes (Tables 4.1 and 4.2 of Presidio Parkway Project (2010b)). Furthermore, the contract documents clearly define the amount of deduction for each and every activity and factor (Appendix 5). The deductions are categorized in the contract documents as shown below.

1. Inspection & Reporting
2. Flexible Pavement Related
3. Rigid Pavement and Bridge Deck Related
4. Slopes, Drainage and Vegetation Related
5. Littering and Debris Related
6. Landscaping Related
7. Storm Water Related
8. Structures Related
9. Tunnel Systems Related

10. ITS and Communications Related

11. Electrical Systems Related

12. Traffic Guidance Related

13. Storm and Other Major Damage Related

14. Incident Response Related

15. Sustainability Management Plan Reporting Related

The deductions are heavier if the unavailability occurs during rush hours, but they are lighter during the off rush hours (Appendix 6).

Although an extensive list of disruptive events contributing towards non-availability of highways and their frequencies are available in project documents, the probability of occurrence of these events is not available. Several data sets were accessed to obtain probability of occurrence of events that can reasonably fit the Presidio Parkway's climatic conditions and type of pavement, but such data was not available. Hence, it was decided to assume a reasonable probability distribution for deductions. The selection of probability distribution was influenced by the following factors:

The deductions would have an upper limit and a lower limit. Hence, the distribution for deductions must be a closed distribution. This mandates that we can only use distributions such as Uniform, Triangular or Beta distribution to represent deductions.

If an efficient private sector wins the bid, the mean of the deduction for such a private sector would be much lower. On the other hand, if the private sector is inefficient, the mean of the deductions would be much higher. Since at this stage (i.e., before bid award) the public sector does not know anything about the private sector's efficiency, assuming any value of mean (high or low) could lead to several issues. If the mean is selected high, the model would consider higher deductions and thus represent an inefficient private sector. This would imply that when higher values of deduction are fed in the MOSDP model, the model might (very likely to occur) design higher MAP for the contract. This could mean that since the mean of deduction was set at a higher value, the public sector pays higher MAPs to hedge the risk of private sector's failure. On the other hand, the scenario where the deductions are selected lower conveys that the private sector is highly efficient and thus the model might (very likely to occur) design smaller MAPs increasing the risk of private sector failure. Therefore, for this case study it is inappropriate to assume a mean of the deductions. This implies that using discrete uniform distribution would be most appropriate. Additionally, the use of discrete uniform distribution enables allocating equal probability to each and every outcome that was considered to be appropriate for the analysis.

In addition, when solving the MOSDP using probabilities, the calculations would include the distributional effects of the deductions. Hence, analysis will be conducted considering discrete uniform distribution and triangular distribution. In addition, the results might show some interesting changes if the values of random variables are simulated considering different distributions. So, when using MO$\tilde{S}$DP model, the analysis will be conducted considering discrete uniform distribution and triangular distribution.

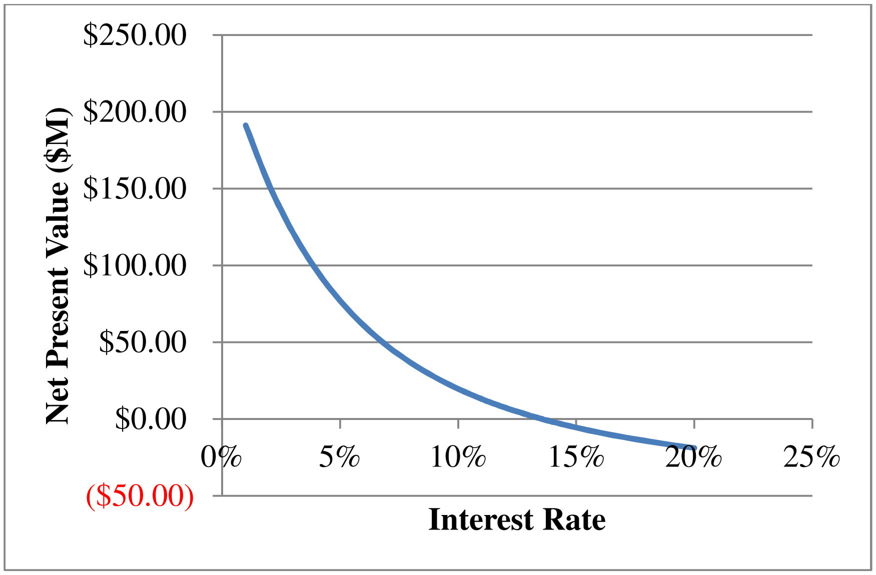


**Figure 13 NPV of Equity Cash Flows (With 100% Highway Availability)**

To use the distributions, we must estimate the parameters of the distribution. Since the distributions should be closed, it will be necessary to estimate the range of the distribution. For Presidio Parkway Project, the minimum value of deduction is zero but we must also estimate the maximum value of deduction. This was done by developing and using equity cash flow statements.

The equity cash flows were obtained by collecting the information about expenses and costs and then putting them together (Appendix 7). Following calculations were carried out to obtain the equity cash flows:

Expenses

Equity Investment

Construction Cost Financing Charges

+ Taxes

+ Operation Costs

+ Maintenance & Rehabilitation Costs

+ Senior Debt Repayment

+ TIFIA Repayment

Total Expenses

Earnings

Availability Payment (Design and Financing)

+ Availability Payment (O&M Part)

Total Earnings

Equity Cash Flows (Total Earnings - Total Expenses) (4.1)

Several assumptions were made during these calculations since all the information was not available. For example, the profit expected to be earned by the private sector at the end of construction phase has been assumed to be 3% in these calculations. However, it must be noted that the actual construction cost can be much less (and thus the profit may be much higher than the 3% assumed here) and since the project jobs are subcontracted (or even sub-subcontracted) it might happen that the profits added at every level of subcontracting might increase the overall profit margin to very high levels.

In the case of the Presidio Parkway Project, the private sector's equity cash flows (Table 3) show that the private sector will get an IRR of 13.56% (for 100$% availability of highway). This number is obtained by developing an equity cash flow statement using government documents that were prepared when the private sector was not known. The value of 13.56% was derived by making assumptions about the private sector's profit margin and its financial structure. Hence, a value of 13.56% has been accepted here for this research work with reservations. Assuming that the private sector will not want to work at an IRR of less than 11.50%, we want to estimate the yearly deductions that would reduce the private sector's IRR from 13.56% to 11.50%.

**Table 3 Equity Cash flow For The Private Sector**

| Year | Equity Cash Flow ($M) | Year | Equity Cash Flow ($M) | Year | Equity Cash Flow ($M) |
|---|---|---|---|---|---|
| 2009 | -50.00 | 2021 | 7.62 | 2033 | 9.67 |
| 2010 | 0.00 | 2022 | 6.40 | 2034 | 8.50 |
| 2011 | 0.00 | 2023 | 7.93 | 2035 | 10.07 |
| 2012 | 0.00 | 2024 | 6.72 | 2036 | 8.91 |
| 2013 | 15.95 | 2025 | 8.25 | 2037 | 10.49 |
| 2014 | 14.95 | 2026 | 7.04 | 2038 | 9.33 |
| 2015 | 17.11 | 2027 | 8.58 | 2039 | 10.92 |
| 2016 | 5.55 | 2028 | 7.38 | 2040 | 9.77 |
| 2017 | 7.71 | 2029 | 8.92 | 2041 | 11.37 |
| 2018 | 5.75 | 2030 | 7.73 | 2042 | 10.23 |
| 2019 | 7.98 | 2031 | 9.29 | 2043 | 16.47 |
| 2020 | 6.10 | 2032 | 8.11 | | |

The annual deductions that would drop the private sector's IRR from 13.56% to 11.5% came out to be $1.66M. The equity cash flow values obtained by deducting $1.66M from the above Table 3 would be useful to construct the lower boundary for the model (discussed in Section 4.2.2.1).

#### 4.2.1.3 Variation in Private Sector's Financial Status

The variation in the private sector's financial variation is the difference between $CFS_{t+1}$ and $FSA_{t+1}$, as discussed in Section 3.3.2 and described using Figure 5. The variation is dependent on private sector's performance and thus the deductions. It was observed that the formula that calculates variation (equation 3.4) includes $MAP^1$, $FSR_{t-1}$, $CFS_{t-1}$, $FA^s{}_t$, and deductions. Notice that the variation in state at any stage t would only depend on $FSR_{t-1}$ and the deductions since all other terms are constants. Other terms must be obtained and are described below:

The $MAP^1$ for this project is $35.53M (as described in Section 4.2.1.1).

The $FSR_{t-1}$, which stands for Financial State Realized, is a value that would be realized at stage t-1. The model would generate this value on its own representing the private sector's financial condition.

$CFS_{t-1}$, which stands for Control Financial State, represents the state at which the public sector wants the private sector to be. The values of CFS can be linked to the expected private sector's performance indicators (as discussed in Section 3.5) and an appropriate value can be derived. However, since the current case study calculations are carried out at a time when the private sector was not known, the CFS value must be selected with some judgment. If the private sector is expected to be very efficient, the CSF value can be set near the lower boundary (as shown in Figure 5). Conversely, if the private sector is expected to be not so efficient, the CFS must be set up more towards the upper boundary.

Setting up the value of CSF towards the lower boundary would mean that if the private sector's financial state is lower, the model would recognize very small values of variation and might select smaller MAPs more often. But, if the CSF is set up near the upper boundary and if the private sector's financial state is low, the model might pick up larger MAPs to reduce the variations. For this research work, the CFS was selected to be approximately between the model's lower boundary and one eighth of the deduction.

In this research work five MAPs were considered: \$33.93M, \$34.33M, \$34.73M, \$35.13M and \$35.53M. It was necessary to consider each MAP during analysis. When solving the MOSDP problem manually, we could conveniently use each MAP value and find the results. However, MS Excel was used in this research to model the problem and because of the modeling constraints, it was necessary to introduce a term that could identify each MAP. Hence, the term $FA^{P}_{t}$ was introduced in the calculations that just represented the difference between the MAPs. Hence, $FA^{P}_{t}$ for the current case study can be calculated as below:

$FA^{1}_{t}$ for $MAP^{1} = 35.53 - 35.53 = 0.00$

$FA^{2}_{t}$ for $MAP^{2} = 35.13 - 35.53 = -0.40$

$FA^{3}_{t}$ for $MAP^{3} = 34.73 - 35.53 = -0.80$

$FA^{4}_{t}$ for $MAP^{4} = 34.33 - 35.53 = -1.20$

$FA^{5}_{t}$ for $MAP^{5} = 33.93 - 35.53 = -1.60$

The $FA^p_t$ values used above are valid if the difference between two stages is one year. However, for our analysis the difference between two stages will be five years and, hence, $FA^p_t$ values calculated above must be multiplied by 5.

The deductions have already been discussed in the previous section.

### 4.2.2 The Constraints

Two sets of constraints are used in this research work. The first set of constraints defines the lower and upper boundary for the model (thus protecting public and private sector interests respectively); the second constraint enables the model to consider post-concession maintenance costs in the model. Both constraints are discussed in the following paragraphs:

#### 4.2.2.1 Determining States and Stages

Section 3.2.5 discusses selecting stages and states for the model. Following the description, the O&M period of the model was divided into six stages. For each stage, it was required to estimate the financial states that can be expected. To calculate the states, equity cash flow statements were used.

Section 4.2.1.2 provided information about developing equity cash flow statements. The values of equity cash flows for 100% availability of highway (i.e., no deduction) are displayed in table 4. If these values are used and added every year, we obtain the cumulative values of the private sector's finances representing the upper limit (since there is no deduction). On the other hand, if we apply yearly deductions of $1.66M to the equity cash flow statement for the whole O&M period we can obtain the equity cash flow statements representing the lower limit of the private sector's financial condition. By adding these values we obtain cumulative values that form a boundary representing the private sector's financial lower limit. The following table provides the boundaries obtained using this approach for Presidio Parkway Project.

**Table 4 Cumulative Equity Cash Flow with No Deductions and with Max. Allowable Deductions**

| Year | Best Case (No Deduction) | With Deductions (Max $1.66M) |
|---|---|---|
| 2009 | -50.00 | -50.00 |
| 2010 | -50.00 | -50.00 |
| 2011 | -50.00 | -50.00 |
| 2012 | -50.00 | -50.00 |
| 2013 | -34.05 | -35.72 |
| 2014 | -19.10 | -22.43 |
| 2015 | -1.98 | -6.98 |
| 2016 | 3.57 | -3.09 |
| 2017 | 11.28 | 2.96 |
| 2018 | 17.02 | 7.04 |
| 2019 | 25.00 | 13.35 |
| 2020 | 31.10 | 17.79 |
| 2021 | 38.72 | 23.74 |
| 2022 | 45.12 | 28.48 |
| 2023 | 53.05 | 34.74 |
| 2024 | 59.77 | 39.80 |
| 2025 | 68.02 | 46.38 |
| 2026 | 75.06 | 51.76 |

| Year | Best Case (No Deduction) | With Deductions (Max $1.66M) |
|---|---|---|
| 2027 | 83.64 | 58.67 |
| 2028 | 91.02 | 64.39 |
| 2029 | 99.94 | 71.64 |
| 2030 | 107.67 | 77.71 |
| 2031 | 116.96 | 85.33 |
| 2032 | 125.07 | 91.78 |
| 2033 | 134.74 | 99.78 |
| 2034 | 143.24 | 106.62 |
| 2035 | 153.31 | 115.02 |
| 2036 | 162.22 | 122.27 |
| 2037 | 172.71 | 131.09 |
| 2038 | 182.04 | 138.76 |
| 2039 | 192.96 | 148.01 |
| 2040 | 202.73 | 156.12 |
| 2041 | 214.09 | 165.82 |
| 2042 | 224.32 | 174.39 |
| 2043 | 240.80 | 189.19 |

#### 4.2.2.2 Determining Post-Concession O&M Costs

As described in the sections 3.2.4 and 3.3.3.2, the duration of concession will have a direct impact on the RSL costs. The longer the duration, the lesser the maintenance costs will be. The cost of maintenance expected for periodic maintenance of a highway can be calculated using NCHRP 688 or other guidelines/manuals developed by the State Agencies. However, this is not required since project documents shows that the remaining life cycle costs for this project will be $591M.

### 4.2.3 Assumptions

The following assumptions were made during the analysis:

a) Deductions were assumed to follow uniform discrete distribution (triangular distribution will also be considered at a later stage).

b) The private sector earns 3% of construction costs ($501) as profit before the operations phase.

c) The private sector expects a MARR of 11.5%. (Note that as per the equity cash flows, the private sector gets IRR of 13.56%). Hence, the private sector expects annual deductions not more than $1.664M.

d) Events causing deductions are independent of each other.

e) The concept of "roll-over" of funds saved due to smaller deductions was not allowed here. This means that if in the initial years deductions are very small, then the extra earning/savings will not be allowed to cover for larger deductions occurring during the later years.

f) The calculations displayed above did not change the distribution of deductions through the stages. However, the model is developed in such a way that distribution can be changed at every stage.

### 4.3 Model Calculations

Once all the information about the Presidio Parkway Project is available, we can begin with the backward-pass calculations. The following explanation focuses on using expected values during calculations and thus it explains the MODDP model. The changes that must be considered when using other forms of the hybrid model will be discussed towards the end of this section.

The backward-pass calculations start from the last stage and then move towards the beginning of the project. The following steps were taken to during the backward-pass calculations:

1. Divide concession in stages

For this research, we divided the concession into six stages.

2. Calculate possible states

We start with the last stage. As per table 4 we can see that at stage 6 (year 2038) there will be 53 financial states, since the model can take values from 138 to 182.

3. Calculate expected deduction

In this research work we have considered deductions as random variables and are assumed to follow the discrete uniform distribution as explained in Section 4.2.1.2 (Note: the triangular distribution would also be used to estimate the effect of change in distribution on the overall results). In this case study, we use the lower limit of deductions as 0, i.e., the parameter a = 0. The deductions can be as high as the value of the MAP. As explained in Section 4.2.1.2, the maximum acceptable annual deduction of $1.66M will represent the parameter b of discrete uniform distribution. Thus, we get the expected deductions as:

Expected Deduction $= d_1p_1 + d_2p_2 + \ldots\ldots dnpn$

$d_1, d_2 \ldots.$ dn are the discrete deduction that can occur

$p_1, p_2 \ldots. p_n$ are the probabilities associated with the discrete values of deduction

$d_1$ = Minimum Deduction = 0

$d_n$ = Maximum Deduction = $1.66M

Expected Deduction = (0/167)+(0.01/167)+(0.02/167)+…+ (1.66/167)

= $ 0.83 M

4. Create a table consisting of all combinations of states and decision variables. This leads to the following table. [Note: since the difference between two stages is 5 years the values are multiplied by 5 during calculations

**Table 5 Part of MOSDP at Stage 6**

| State | Decision Variable | Objective 1 | Objective 2 | Combined Objective Function | Future Expected State | Objective Function (Adding Current & Next Stage) | Decision and Objective Function | |
|---|---|---|---|---|---|---|---|---|
| Financial Condition | MAP | Equation (3.2) | Equation (3.3) | Equation (3.1) [i.e., $w_1$Obj.1 + $w_2$Obj.2] | Equation (3.4) | Equation (3.10) | Minimum Objective Function | Best MAP |
| 182 | 33.93 | 165.5 | 31.61 | 152.111 | 229 | 684.011 | 684.011 | 33.93 |
| 182 | 34.33 | 167.5 | 33.61 | 154.111 | 231 | 686.011 | | |
| 182 | 34.73 | 169.5 | 35.61 | 156.111 | 233 | 688.011 | | |
| 182 | 35.13 | 171.5 | 37.61 | 158.111 | 235 | 690.011 | | |
| 182 | 35.53 | 173.5 | 39.61 | 160.111 | 237 | 692.011 | | |
| 181 | 33.93 | 165.5 | 30.61 | 152.011 | 228 | 683.911 | 683.911 | 33.93 |
| 181 | 34.33 | 167.5 | 32.61 | 154.011 | 230 | 685.911 | | |
| 181 | 34.73 | 169.5 | 34.61 | 156.011 | 232 | 687.911 | | |
| 181 | 35.13 | 171.5 | 36.61 | 158.011 | 234 | 689.911 | | |
| 181 | 35.53 | 173.5 | 38.61 | 160.011 | 236 | 691.911 | | |
| ⇓ | | | | | | | | |
| 139 | 33.93 | 165.5 | 11.39 | 150.089 | 186 | 1E+12 | 685.189 | 34.73 |
| 139 | 34.33 | 167.5 | 9.39 | 151.689 | 188 | 1E+12 | | |
| 139 | 34.73 | 169.5 | 7.39 | 153.289 | 190 | 685.189 | | |
| 139 | 35.13 | 171.5 | 5.39 | 154.889 | 192 | 686.789 | | |
| 139 | 35.53 | 173.5 | 3.39 | 156.489 | 194 | 688.389 | | |

Note: $w_1$ = 0.9 and $w_2$ = 0.1 (for all the calculations)

**Table 6 Part of MOSDP at Stage 5**

| Financial Condition (State) | Decision Variable (MAP) | Objective 1 | Objective 2 | Combined Objective Function | Future Expected State | Objective Function (Adding Current & Next Stage) | Minimum Objective Function | Best MAP |
|---|---|---|---|---|---|---|---|---|
| 135 | 33.93 | 165.5 | 24.15 | 151.365 | 170 | 834.176 | 834.176 | 33.93 |
| 135 | 34.33 | 167.5 | 26.15 | 153.365 | 172 | 836.376 | | |
| 135 | 34.73 | 169.5 | 28.15 | 155.365 | 174 | 838.576 | | |
| 135 | 35.13 | 171.5 | 30.15 | 157.365 | 176 | 840.776 | | |
| 135 | 35.53 | 173.5 | 32.15 | 159.365 | 178 | 842.976 | | |
| 134 | 33.93 | 165.5 | 23.15 | 151.265 | 169 | 833.976 | 833.976 | 33.93 |
| 134 | 34.33 | 167.5 | 25.15 | 153.265 | 171 | 836.176 | | |
| 134 | 34.73 | 169.5 | 27.15 | 155.265 | 173 | 838.376 | | |
| 134 | 35.13 | 171.5 | 29.15 | 157.265 | 175 | 840.576 | | |
| 134 | 35.53 | 173.5 | 31.15 | 159.265 | 177 | 842.776 | | |

⇓

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 100 | 33.93 | 165.5 | 10.85 | 150.035 | 135 | Not Feasible | 838.024 | 35.53 |
| 100 | 34.33 | 167.5 | 8.85 | 151.635 | 137 | Not Feasible | | |
| 100 | 34.73 | 169.5 | 6.85 | 153.235 | 139 | 838.424 | | |
| 100 | 35.13 | 171.5 | 4.85 | 154.835 | 141 | 838.224 | | |
| 100 | 35.53 | 173.5 | 2.85 | 156.435 | 143 | 838.024 | | |

Notice that in Table 5 the heading consists of two rows and the second row provides reference equations used to derive the values. The steps are repeated again for stage 5 and we obtain a similar table. However, the calculations are briefly explained in the following section.

5. Use Recursion Formula To Link Two Stages

Consider the situation when the Financial State at stage 5 is 100. In that condition, if the MAP options of $33.93M and $34.33M are used, the project will end up at states 135 and 137, respectively (column 6 of table 6). Since these states do not exist in stage 6, the model would not find any value when it uses the recursion formula. In practical terms, this means that the partnership would break.

However, if the option of $34.73M is offered, the project would have a state of 139 during stage 6. The recursion formula of the model would now search the state of 139 in the stage 6 table, find the value of objective function that would be minimum and add it with the objective function for stage 5.

From table 5, it is evident that during stage 6 for a state of 139, the minimum objective function value is 685.189 (for MAP of 34.73). Hence, during stage 5 calculations, we use a value of $685.189M from stage 6 and add it with the current value of objective function, which is 153.235 (Column 5). By adding these two values, we get $828.424M. Similar calculations can be done when the project would have states of 141 and 143. When we compare the objective value functions (column 7), we observe that 838.024 is the lowest value of the objective function and hence we must select MAP of $35.53M during stage 5.

These steps can be repeated for all the states (from 100 to 135) for stage 5. This would give us all the values for all the states in stage 5. Notice that by using the recursion formula in column 7 we are actually adding the objective function value up to stage 5 (column 5) with the expected values of objective function for the remaining stages.

These steps must be repeated for stages 4, 3, 2, and then 1. Once we reach stage 1, we complete the analysis and we obtain a solution set. The solution calculations for all the stages and states are included in Appendix 8.

## 4.4 Results and Analysis

Appendix 8 includes all the calculations for the backward-pass and the final solutions. Using these solution sets, we can determine the optimal MAP. Assuming that the private sector enters the construction phase with a financial state of -$34M (negative sign implies that the private sector has not yet reached the breakeven point), we can observe that the optimal solution would consist of following MAPs:

**Table 7 Optimal MAPs Selected By MODDP Model**

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
|---|---|---|---|---|---|---|
| Optimal MAPs ($M) | 34.73 | 35.13 | 34.73 | 34.73 | 34.33 | 33.93 |

When this model was developed, it was expected that the model would select MAPs that would remain very close to the control points throughout all the stages. However, the optimal MAPs that became a part of the optimal solution varied unexpectedly. Hence, it was not possible to identify one convincing MAP as a solution.

Table 7 provides the stage-wise occurrence of each MAP. It is evident from the above table that if we consider the MAP occurring during Stage 1 as our Design MAP, then we should select $34.73M. Also, this MAP occurred maximum number of times (3 out of 6 times) during the concession.

This solution perfectly fits with the actual PPP practice where the MAPs are contractually finalized during the bidding phase and remains unchanged throughout the concession term. However, the MAPs during stage 5 and stage 6 are smaller than the MAP of $34.73M, hence, if MAP of $34.73M is adjudged as the optimal MAP, then we would miss the cost savings realized towards the end of concession. Hence, the MAPs were averaged to estimate the MAP. The model could have been modified to discourage change of MAPs during the concession term by introducing a penalty constraint. The penalty function would have been introduced using the following if-then-else logic:

*If* the changing MAPs is costs less than penalty

*and* changing MAPs would not increase financial variation for the private sector

*then* change the MAP

*else* continue with the same MAP

(4.2)

This might require inclusion of some binary variables that would impose a penalty if MAPs are changed (by taking a value of 1) and would have not affected the results if MAPs did not change (by taking a value of 0). However, adding additional penalty constraint mandated the use of actual amount of money required to make contractual changes. These details are not available (especially in the United States) since PPPs are new to the United States, and there are very few examples where contractual changes were made to PPPs and the extra amount incurred due to contractual changes is generally not easily available or, if it is available, then it is categorized as transaction costs that also include several other contractual fees. Hence, the design MAP was obtained by using the average of values obtained during the analysis. This gives us a design MAP of $34.597M.

In the previous paragraphs, the analysis was conducted on the basis of several assumptions. One of the assumptions included using expected value of deductions. This assumption closely resembles the industry practice of using expected values. In addition the approach is very similar to the deterministic approach described by Winston (Winston, 2004). So the approach and the model described above would be referred as Multi-objective Deterministic Dynamic Programming model (MODDP). It is a known fact that when deterministic approach is used the analysis would yield values ignoring the randomness. Hence, the analysis discussed in Section 4.3 was repeated again to include probabilities into calculations and thus get stochastic solutions for the problem at hand.

In the revised analysis, two different approaches i.e., MOSDP and MO$\tilde{S}$DP were used. In the first approach the model was run again, but this time probabilities were included in the analysis and the model was run such that for each state the deductions were varied between the upper and lower limits. For each discretized value of deduction, objective function values were calculated for all the remaining stages. These objective functions values were multiplied by the probabilities of their occurrence (thus satisfying the second part of recursion formula (3.11)) and then stored in a temporary variable. The process was repeated for all the values of deductions and the values were cumulatively added to the temporary variable. Thus upon analyzing the whole range of deductions, we would get a stochastic value of future's possible stages. Using this approach for all other states and all the stages (going from last stage to first stage) would complete the analysis and would provide a stochastic solution. This approach, of solving the model 3.11 will give us stochastic solution and hence justifies the name Multiobjective Stochastic Dynamic Programming (MOSDP) model. Since this approach requires several iterative calculations for each state, VBA Excel Macros were developed to automate the process.

**Table 8 Optimal MAPs Selected by MOSDP Model**

| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 |
|---|---|---|---|---|---|---|
| Optimal MAPs ($M) | 35.13 | 34.73 | 34.73 | 34.73 | 34.73 | 34.33 |

As described in the MODDP case, here also the values changed throughout the concession term and hence the average was taken. This gives us the Design MAP of $34.73M.

In the second approach randomly generated deductions following different distributions (discrete uniform and triangular) were used instead of using probabilities or using expected deductions. This would allow the model to go through extreme values of deductions and thus provide solutions that can be used for hedging extreme risks of failure. Here also a VBA Excel Macro was developed to automate the process and Monte Carlo Simulations were used. Using the Macros 1000 backward propagation cycles were run and results as displayed below were obtained.

**Table 9 Distribution of MAPs (MO$\tilde{S}$DP model)**

| Decision Variable | Occurrence Of Each MAP During Each Stage | | | | | | |
|---|---|---|---|---|---|---|---|
| | Stage 1 | Stage 2 | Stage 3 | Stage 4 | Stage 5 | Stage 6 | Total Occurrence During the Concession Period |
| MAP = 33.93 | 109 | 32 | 37 | 154 | 329 | 964 | 1625 |
| MAP = 34.33 | 241 | 205 | 213 | 228 | 212 | 36 | 1135 |
| MAP = 34.73 | 267 | 223 | 230 | 239 | 209 | 0 | 1168 |
| MAP = 35.13 | 222 | 254 | 218 | 201 | 142 | 0 | 1037 |
| MAP = 35.53 | 161 | 286 | 302 | 178 | 108 | 0 | 1035 |
| Total Occurrence | 1000 | 1000 | 1000 | 1000 | 1000 | 1000 | |

The distribution for these results also shows that if we consider that the MAP that occurred maximum times during Stage 1 must be selected as design MAP, then we should select $34.73M (since it was selected 267 times by the model). But, if we consider maximum occurrence of a MAP through the concession as the criteria for identifying Design MAP', then, we must select \$33.93M (since it was selected 1625 times) as Design MAP'. Here also, since both the criteria are pointing towards different values, it is not very obvious which MAP out of \$35.93M and \$34.73M must be considered as optimal MAP. Hence, the Design MAP' was again obtained by taking average across the concession period. Design MAP' obtained from such an analysis was \$34.6448M.

### 4.4.1 Value of Stochastic Solution

Here, we solved the problem with expected values, probabilistic values and random values. When we use expected values, the problem corresponds to the "Expected Value Problem" defined by Birge and Louveaux (1997) as a problem solved by using expected values for stochastic variables (without any recourse). In addition, the authors also defined Recourse Problems (RP) as a "two-stage problem" wherein the decision-makers must decide "here-and-now" and make a decision. This RP model corresponds (to some extent) with the six-stage MOSDP model used in this research work. The biggest difference between the RP model and the six-staged models used in this research is that – in the RP model stages are considered in sequence but in this research work the stages are considered in reverse sequence. Thus, considering the six-stage MOSDP model as a six-staged recourse problem, we can calculate Value of Stochastic Solution (VSS) as:

$$VSS = EEV - RP \tag{4.3}$$

For the current research, EEV represents the costs to the public sector if the MAPs are obtained using expected values (without recourse, as well). This requires us to use a model that can avoid recourses but use the expected values. This can be done by changing the model described in Section 3.4. The first change required in the model was to remove the stages and run the model as a model covering the full concession period. This would mean that we would just be concerned about the beginning of the concession period and the end-of-concession period. The MOSDP model (equation 3.11) can be changed to fit such a requirement by reducing the stages from six to one and by using the expected values instead of random values. The model obtained by making these changes is included in Appendix 9. This model would graphically look as shown in the Figure 14.

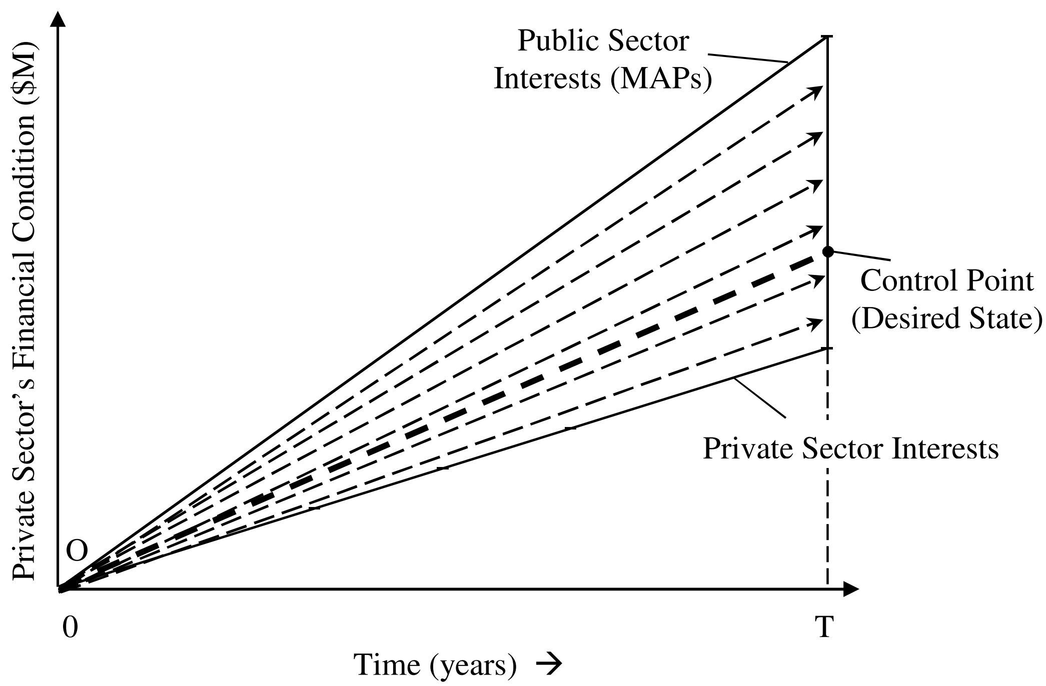


**Figure 14 Single Stage Model Using Expected Deductions (Without Recourse)**

This model gave the objective function value of $1,444.94M representing the EEV for the model. On the other hand when the MOSDP model was run with random values (with recourse) the objective function value of $1,448.53M was obtained representing the RP. This leads us to the following calculations:

VSS = EEV – RP

= (-1444.94) – (-1448.53)

VSS = $3.59M > 0

Notice that the VSS is positive, which indicates that when the MOSDP is used with random values, it gives us more conservative results to manage the randomness. [Note: The VSS of all the analyses conducted in this dissertation are documented in Appendix 10]

### 4.4.2 Pareto Optimality

As discussed in Section 2.6.2, we wish to obtain the efficient frontier from the above analysis. Hence, the models (using expected values and random values) were run again by varying the weights. This helped identify the optimal combinations of public sector costs and financial variations. For the deterministic model, the calculations were done manually which led to the following optimality curve.

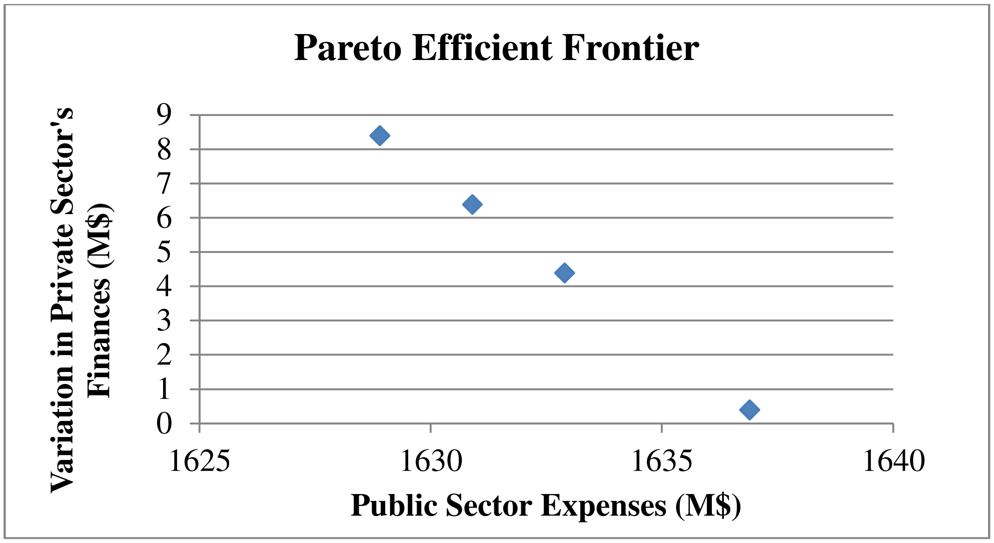


**Figure 15 Pareto Efficient Frontier from MODDP Model**

Then, the line joining the four points defines the Pareto Efficient Frontier. The line can be used by decision-makers to select their strategy depending on their utility.

Similarly, the model developed for allowing probabilistic values as well as random deductions was run for obtaining the Pareto Efficient Frontier. The analysis of the results gave us the following scatter plot.

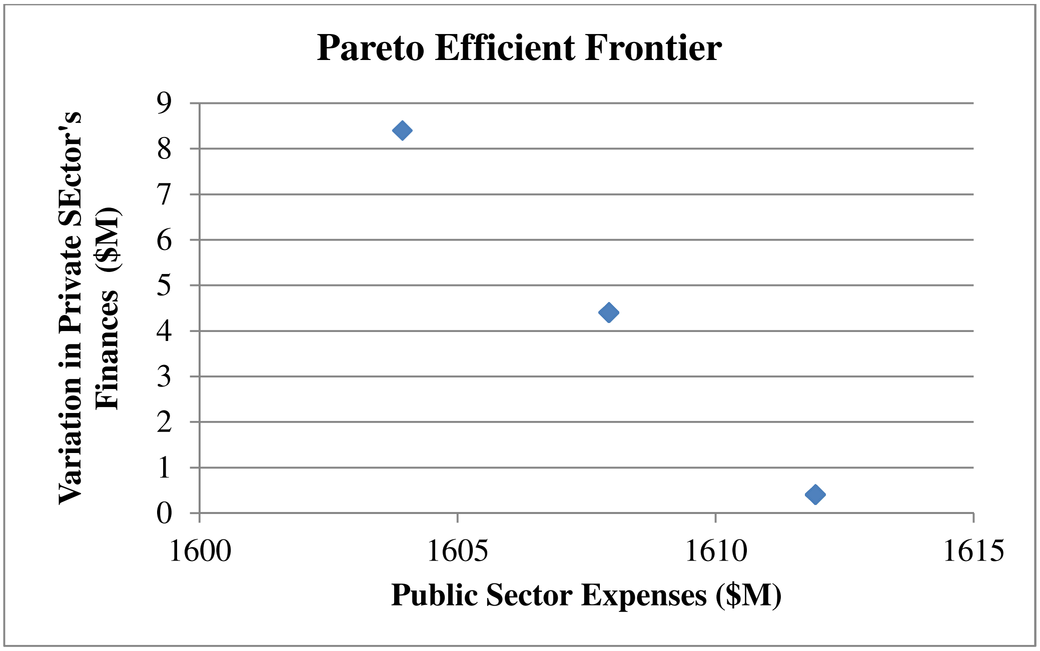


**Figure 16 Pareto Efficient Frontier from MOSDP Model**

The Pareto Efficient Frontier obtained from the MOSDP model resembles closely with the Pareto Efficient Frontier obtained from the MODDP model frontier. In both the cases the frontiers have been obtained by varying the weights from 0.01 to 1.00 and in both the cases we just get a few points that represent the feasible region as well as the Pareto Efficient Frontiers.

The analysis was carried out for MO$\tilde{S}$DP model with the hope to observe the effect of randomness in deductions and various combinations on the Pareto Efficient Curve. The weights were varied between 0.01 to 1.00 in this case also and following feasible region was obtained.

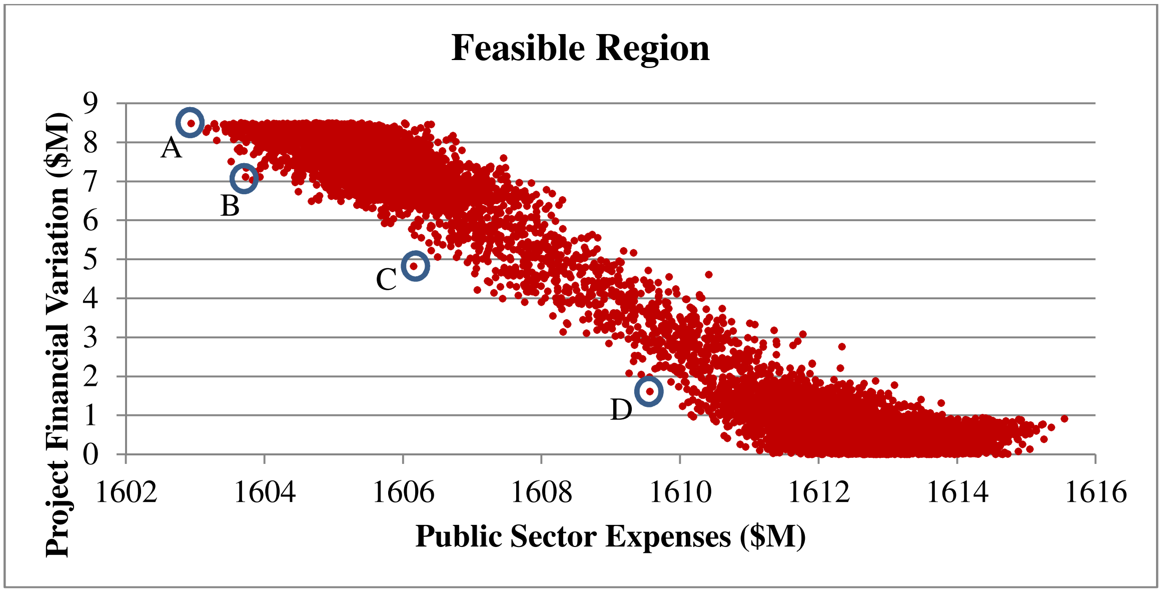


**Figure 17 Pareto Efficient Frontier Considering Random Values**

The curve obtained by joining the selected points (lying towards the south west direction of the feasible region) is believed to approximate the Pareto Efficient Frontier. For a perfect Pareto Efficient Frontier the simulations must be run to an extent ensuring inclusion of every point in the feasible region. This can consume a very large amount of time as compared to the time available to select the concessionaire and sign the contract during bidding. Hence for this research the Pareto Optimal Points obtained from the above analysis are considered acceptable.

The points A, B, C and D highlighted in the graph can be used by decision-makers to select their strategy. For example, if the public sector can allocate about $1606M on the project, then they must use the solution related to point C. Adopting this approach would enable the private sector to experience financial variation of about $4.75M. On the other hand, if the public sector can spend about $1603M, then it is advisable for the public sector to adopt the strategy corresponding to points A or B. Notice, that by adopting point A, the public sector costs would be lesser than the costs associated with point B. However, it must also be realized that by selecting point A instead of point B, the financial variation for the private sector is increasing very rapidly. Hence, the public sector must select the results carefully and consider the tradeoffs associated with each strategy.

### 4.4.3 Effect of Different Distribution on Results

As per the discussion in Section 4.2.1.2, the deductions were assumed to follow triangular distribution. The parameters assumed for the analysis are:

Lower limit of deductions = a = 0

Upper limit of deductions = b = 1.66

Mode = (a+b)/2 = 0.83

The mode is assumed to be located at the center of its range with the intent to avoid making assumptions about the deductions, which seems to be correlated with the private sector's overall efficiency (as discussed in Section 4.2.1.2). With these parameters, the analysis as explained in Section 4.3 was carried out. Since the expected value of deduction following discrete uniform distribution and the mode of deductions following triangular distribution would result in no difference in the MODDP results. This implies that in this case also the Design MAP would be $34.597M. However, when the analysis was carried out using the MOSDP and MO$\tilde{S}$DP models following results were obtained:

**Table 10 Effect of Deduction's Distribution on MAPs**

| Models | Uniform Distribution | Triangular Distribution |
|---|---|---|
| MODDP | \$34.597 | \$34.597M |
| MOSDP | \$34.73M | \$34.73M |
| MO$\tilde{S}$DP | \$34.6448M | \$34.650M |

Comparison shows that, the MAPs designed using MOSDP are giving same values and the MAPs designed using the MO$\tilde{S}$DP models have negligible difference when considering uniform and triangular distribution. If the values are rounded up to the second decimal, we get the same value.

Since the results obtained till now (referring to tables 7 through 10 and figures 15 through 17) shows that the result patterns obtained from MOSDP model shows very high resemblance to the MODDP results while falling between the extremes of deterministic and simulated models, it was decided that for rest of the research work only the MODDP model and the MO$\tilde{S}$DP models would be used.

### 4.4.4 Model Performance

The calculations provided untill now considered only the backward-pass calculations (covering steps 1 to 6 listed in Winston, 2004, and discussed in Section 3.6). As per step 7, the results obtained can now be used to move forward from first stage to second stage and similarly all the way up to the final stage. While moving from one stage to the other, realization takes place (about private sector's performance and also the deductions) and we might find that the project is at a state that was not expected at the beginning. Now, since the project is at a different state, we do the following:

a) establish the state at the current stage, and
b) use the model results already available to us to identify the best strategy (in terms of MAPs) for the remaining concession term.

These two steps when applied through all the stages (moving from first stage to last stage) will allow us know how the project will end if we use the results from this model. In this part since we move from first stage to the final stage, the process is called a realization pass. To accomplish this, macros were developed and the model was run iteratively.

The models were run10,000 times giving us 10,000 optimal solutions. Each run consisted of a backward-pass followed by a realization pass. The models' backward-pass remained the same as descried earlier and the realization pass always used random values of deductions.

*Why Include a Realization Pass in Decision-Making?*

The MAP designed by using the backward-pass is sufficient and can be used directly on the project. But, it would be more beneficial if we enhance our designs by incorporating the "intelligence" regarding:

1. how good will be to use the designed MAP, and

2. how the solution (obtained through backward-pass) guide the decision-makers to change the MAPs.

For example, let us assume that the Design MAP is $32M and the project is in the O&M phase. The designed MAP can be a perfect design or it can be an imperfect design. If the MAP of $32M proves to be a perfect design (a hypothetical case), the realization pass would not have any change in MAPs. However, if $32M is an imperfect design, the solution obtained through the backward-pass would help the decision-makers change the MAP during each stage. Thus, if we refine our design MAPs by incorporating all the intelligence gathered from the realization pass, then our results are expected to get better.

The analysis of 10,000 iterations consisting of a backward-pass followed by a realization pass shows that:

MAP from MODDP models = $34.676M

MAP from MO$\tilde{S}$DP model = $34.689M

These values were obtained using the calculation procedure described in Section 4.4. The following table summarizes the difference between the two sets of results.

**Table 11 Comparison of MAPs On The Basis of Passes**

| | Backward-pass (Uniform Distribution) | Backward & Realization Pass (Uniform Distribution) |
|---|---|---|
| Design MAP using MODDP | $34.597 | $34.676M |
| Design MAP using MO$\tilde{S}$DP | $34.6448M | $34.689M |

The results show that the MAPs designed using backward and realization passes are higher. It is believed here that as the model was run in a forward direction the model could also capture the variation in decisions occurring during the O&M phase. Thus, it is believed that, although the values obtained through both backward and realization pass calculations are higher they would offset the risk of very high changes in MAPs.

### 4.4.5 Validation of Results

The method used above provides some results, but: How good can these results be? This requires that the approach developed above is validated. In order to do so, additional information about the Presidio Parkway project was collected. The information included details about the finalized agreement between Presidio Parkway Project Authority (Caltrans) and Golden Link Partners (a company collectively formed by HOCHTIEF PPP Solutions North America Inc., MINA USA, LLC, Flatiron West, Inc., Kiewit Infrastructure West Co., Scotia Capital Inc., Milbank, Tweed, Hadley & McCloy LLP, Orrick Herrington & Sutcliffe LLP, LeighFisher, TSIB, Moore McNeil, Barclays Capital Inc., Merrill Lynch, Pierce Fenner & Smith Incorporated and Scotia

Capital, Inc.). The finalized agreement document reveals that GLP approached various institutions, with the objective of defining an optimal financial structure for the project and developed a financial structure that ensured a timely debt procurement and financial close. Furthermore, the final documents reveal that the GLP transferred its construction responsibility to Flatiron and Kiewit through a fixed price, date-certain design-build contract. The documents show that this would cost GLP an amount of $254.03M, which is just above half of the $501M expected before the bidding. In addition, it was also observed that the optimal financial structure developed by GLP would cost them a total of about $358M during the construction phase, which is a little more than half of $629M (which includes 501 Construction Costs, $97M for repayment of senior debt, $25M for interests and $6M for fees and other costs), the cost estimated before bidding. These differences in the capital expenses and the optimal structuring of finances would lead to significant savings to GLP. Hence, the model used for base case analysis was revisited and the models were modified to represent project with reduced capital costs.

Models were developed by reducing the construction costs to 50% and 60% and correspondingly the debts (senior and junior) were also reduced. The operating costs, maintenance and rehabilitation costs and the taxes were not changed. This gave us three different models. The models with 50% and 60% costs were the closest to what GLP proposed GLP (since the construction costs and the total funds required during construction were between the 50% and 60% range of the costs expected during bidding). These models were run 97 times and following results were obtained.

**Table 12 Results with Reduced Capital Costs**

| | 50% Cost Reduction | 60% Cost Reduction | Actual MAP |
|---|---|---|---|
| MAP (MODDP) | \$27.56M | \$28.97M | \$28.55M |
| MAP (MO$\tilde{S}$DP) | \$27.51M | \$29.06M | |

It is evident from the above results that the values obtained from the models are very close to the actual MAPs offered by GLP, which is \$28.55M. The results obtained above validate the model and thus can be used to design MAPs with very limited information. It must also be noted here that the values obtained from the models are based on the information available before the concessionaire is known. Hence, it is expected that the model might be able to provide much better results if the model is run after obtaining precise information about the concessionaire.

### 4.5 Summary of the Chapter

This chapter uses Caltrans' Presidio Parkway Project as a case study and demonstrates the use of the hybrid models to design MAPs. The analysis was carried out using expected values as well as randomly generated values of deductions. Comparison of the results shows that the designed MAPs were higher when randomly generated values of deduction were used. In addition, the results also show that the discrete uniform distribution and triangular distribution had a negligible effect on MAP design. Last, the chapter also shows how to design the MAPs using the "intelligence" gathered from the project's performance when using the solutions from backward-pass calculations. The approach was called realization pass. The MAPs designed using backward and realization pass iterations were found to be conservative and are expected to be safer than then results obtained from backward-pass only.

## Chapter5. Design of Concession Period

### 5.1 Introduction

In the previous chapters, a fixed, 30-years' Operations and Maintenance concession period was considered. It is a general practice to fix the concession period early in the project on the basis of heuristics and then carry out analysis for feasibility (analyses like Value for Money (VFM)). The contemporary analyses do not consider estimating the advantages/disadvantages of varying the concession term (HM Treasury, 2006 and Partnerships Victoria, 2001). This chapter of the dissertation specifically focuses on variation of concession length (while keeping all other parameters fixed) and puts forward an approach that will help to determine the most economical concession period.

This analysis will enable the public sector to determine the duration of concession periods. It is very important to design the concession period since each year of concession allows the private sector to retain control over the asset and enjoy several privileges which can go against the public interests. In case of availability payments, during each year the private sector gets paid by the public sector for maintaining the availability of the highway. Hence if the concession term is larger than or shorter than necessary the risk of private sector's making exceptionally high profit through public funds or private sector's failure increases respectively. In either case, it is a loss to the public. Hence it is very important to consider concession term as an important parameter in all the PPP analysis. This chapter is dedicated towards design of concession term. The analysis uses the model described in the previous chapter and establishes a method that will enable the public sector to determine the most economical concession term along with the determination of optimal MAP.

### 5.2 Importance of Considering Variation of Concession Term During Analysis

Highways require regular as well as periodic maintenance. The regular maintenance activities are required very frequently, consume very short time spans and are relatively cheaper. On the other hand the periodic maintenance activities are required at predetermined intervals and are very expensive. The interval between two periodic maintenance activities depends on factors such as preventive maintenance of highways, pavement type, climatic condition, highway use and several others. Since the periodic maintenance costs are very expensive the inclusion or exclusion of these costs can make a significant impact on the overall highway life cycle costs. Observe the Figure 18 adopted from Li & Kaini (2007). The figure shows periodic maintenance costs over the lifecycle of a highway. The figure shows that as the years pass, the Pavement Condition Index (representing the condition of the pavement) decreases. The pavement condition improves significantly when periodic maintenance activities are carried out. The deterioration and maintenance cycles continue several times and represent the life cycle of the highway. Generally the life cycle of highways is larger than concession terms in PPPs with Availability Payment mechanism. In these conditions, it is necessary to determine the duration of concession term since the inclusion or exclusion of a periodic maintenance activity can make large difference financially.

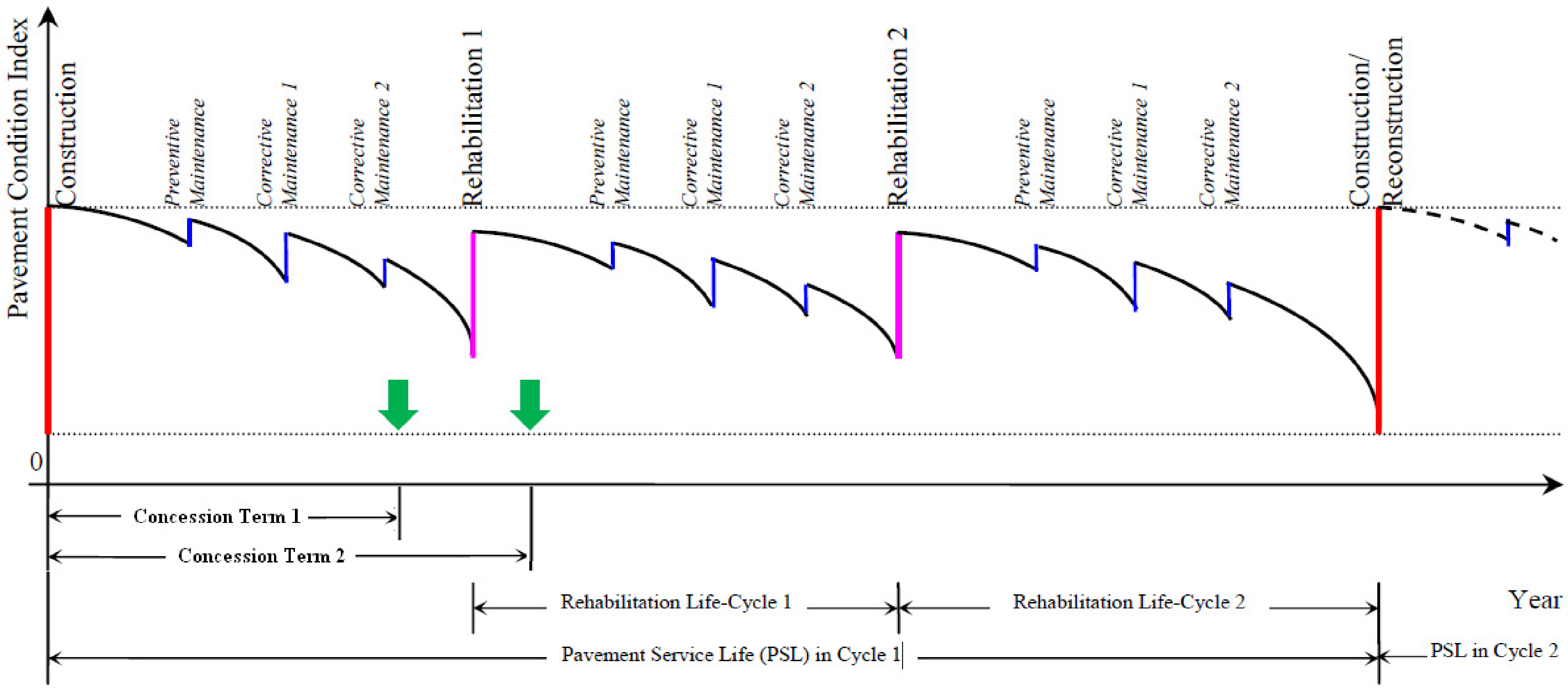


**Figure 18 Lifecycle Maitnenance Activities For A Highway**

Consider that the concession term of a PPP ends a few years before the first major rehabilitation (Concession Term 1 in Figure 18). As a result the public sector owns the responsibility to rehabilitate the highway immediately after the transfer of the highway. However, if the concession term ends a few years after the first major rehabilitation (Concession Term 2 in Figure 18) the public sector gets a newly rehabilitated highway after the transfer. It is reasonable to assume here that the experience gained by the private sector towards maintaining the highway throughout the concession period may make the private sector more efficient to carry out the rehabilitation which could reduce the overall costs of the highway. This could prove to be a win-win condition for the public sector as well as the private sector since the private sector gets an opportunity to use its experience and establishment to carry out additional work at a higher efficiency and the "public sector" reduces the overall inhouse costs (which may prove much higher than private sector due to lack of experience and lesser efficiency) and risks associated with rehabilitation. In these conditions it is beneficial to increasing the concession term. However, longer concession duration empowers the private sector to control the asset for longer duration which could go against the public interests. Furthermore, each additional year of concession would make the private sector eligible to Operate and Maintain the highway and upon satisfactory performance, entitle them to receive Availability Payments. In such conditions it is necessary to design concession term appropriately.

Furthermore, it is evident from the figure adopted from Li & Kaini 2007 that before the two major rehabilitation jobs the highway passes through several preventive as well as corrective maintenance jobs. The preventive and corrective maintenance keep the highway in good condition and help in delaying the rehabilitation of pavement. The delay helps in reducing the overall highway live cycle costs due to the Time Value of Money effect. Although having preventive maintenance program in place is beneficial, the DOTs are sometimes forced to avoid preventive maintenance due to financial constraints. This reduces DOTs' maintenance costs but accelerates pavement deterioration forcing the DOTs to rehabilitate the highway earlier. In these circumstances it is better to pass on the operation and maintenance responsibility to the private sector that would be willing to invest money towards preventive maintenance resulting in better highway condition. When the highways are maintained well the investment intensive rehabilitation can be delayed which contributes towards overall reduction of life cycle costs. Hence it can be beneficial to increase the concession term. However, since each additional year of concession can prove costly to the public it is necessary to design the concession term using appropriate tools.

### 5.3 Analysis to Determine The Most Economical Concession Term

In order to select the most economical concession term the Multi-Objective Stochastic Dynamic Model framework described in Section 3.2 was used again. The analysis was carried out through the following steps:

1. Determining the maintenance costs for the highway.

2. Models were set up to have concession terms less than 30-years as well as more than 30-years.
3. In each model, appropriate arrangements were made for randomly generated Deductions to follow Discrete Uniform Distribution.
4. The model was run 1000 times and during each run (Backward-Pass and then Realization Pass) simulated values of deductions were used.
5. Highway lifecycle costs were estimated. The lifecycle costs fully enclosed the PPP concession term.
6. Lifecycle costs for projects with different concession terms were compared which enabled the identification of concession term costing least.
7. Using the identified concession term use the value of optimal MAP (determined in steps 2 and 3) and use the combination of identified concession term and Optimal MAP bidding and/or negotiating.

Notice that in steps 3 and 4 the models with different concession periods are run. These steps are just the repetition of steps described in Sections 4.3.2 and 4.3.3. The results obtained in steps 3 and 4 are compared to identify the best alternative. In the whole process, only the setting up of the models and comparison of results differs. Hence the following part of this section explains the process of setting up of models with different concession terms (Step1 and 2), comparison of results and selection of the best alternative (Steps 4 through 6). Following part of this section continues with the case study and provides details for setting up these models.

### 5.4 Determining the Maintenance Costs

In case of Presidio Parkway Project the high periodic maintenance costs are expected to occur at regular intervals. The cost profile is shown in figure 19. The figure shows that the maintenance costs are forming peaks due to periodic maintenance and major rehabilitation activities but remain at very low levels for routine maintenance activities.

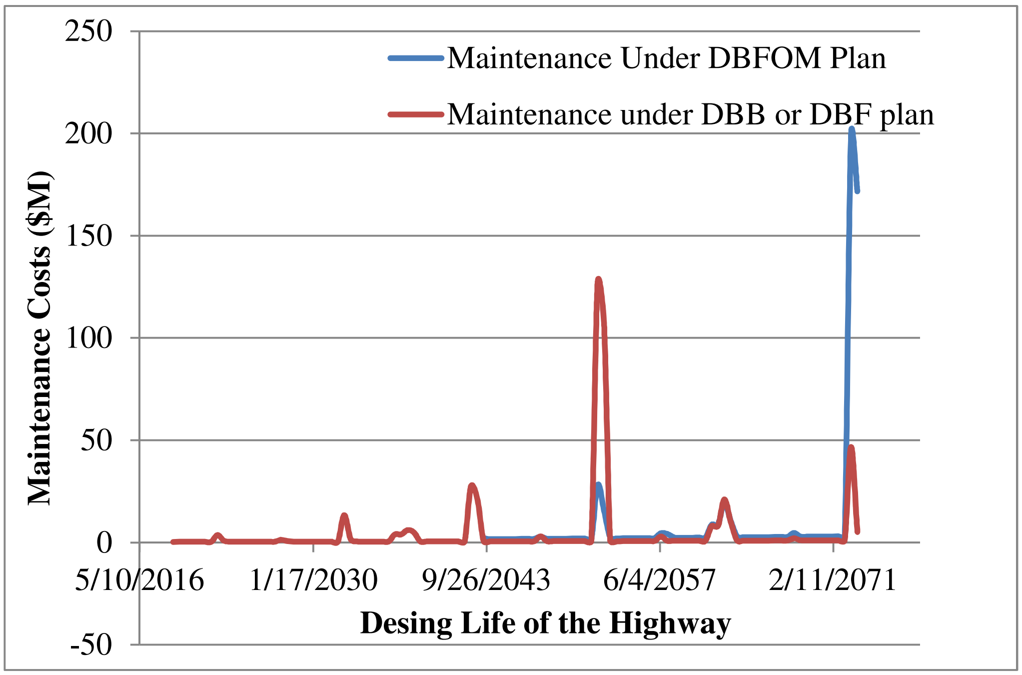


**Figure 19 Periodic Maintenance Costs for Presidio Parkway Project**

Under DBFOM PPP the public sector's maintenance responsibility would start in 2043. As per the DBFOM plan the private sector would be responsible for preventive maintenance also which would push the investment intensive highway rehabilitation to years 2072 and 2073. On the other hand when other options such as DBB or DBF are considered for project delivery the public sector retains full responsibility of operating and maintaining the highway. Since the public sector (CALTRANS) expects financial challenges the Preventive Maintenance is ignored under these project delivery options which accelerates the pavement deterioration and forces the public sector to perform the investment intensive maintenance activities much earlier. The costs associated with these two PPP options can be seen in Figure 19. However, for clarity and to avoid overlapping of graphs the two cost scenarios are plotted separately as shown below:

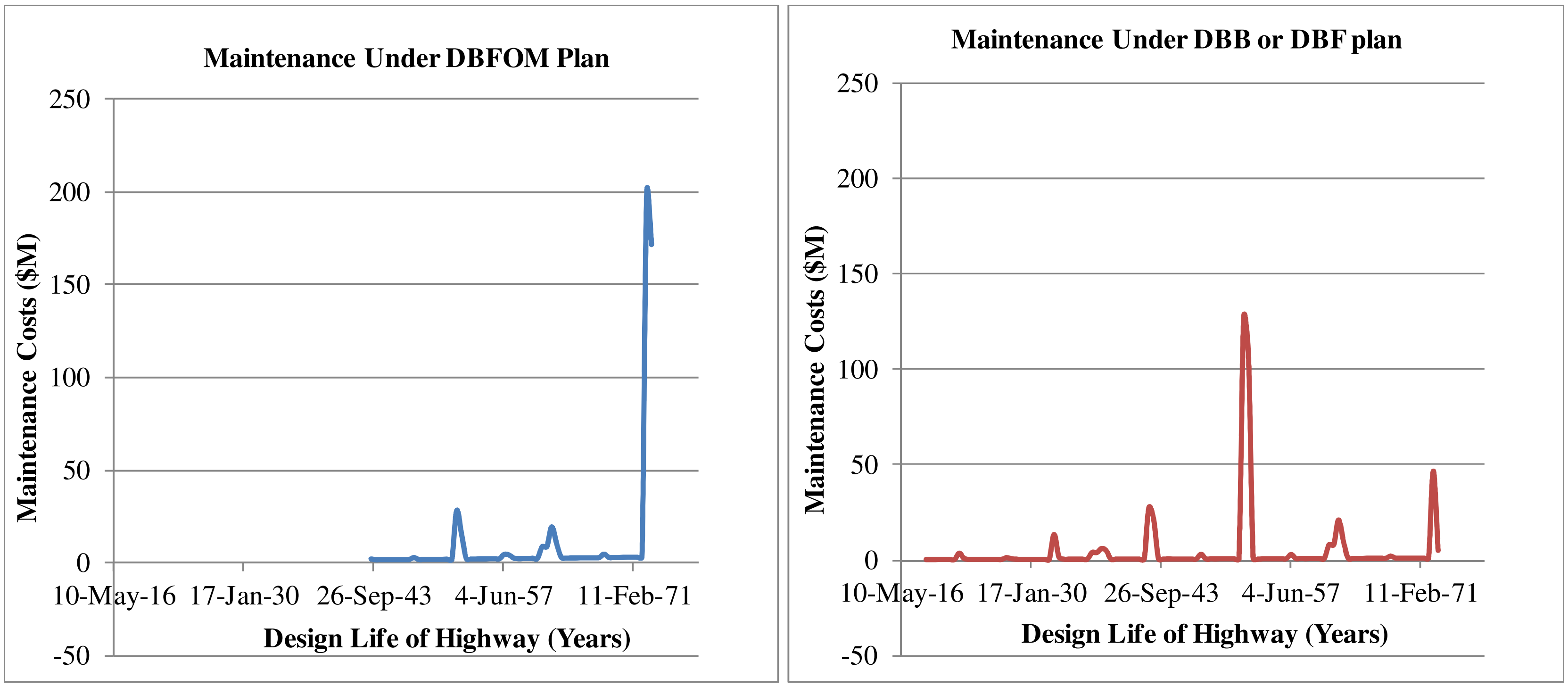


**Figure 20 Mainteanance Costs of Presidio Parkway Project**

In the current condition the DBFOM PPP with concession of 30-years can be shown graphically as shown in Figure 20. The figure shows that as the concession term ends after 30-years (in the year 2043) the public sector becomes responsible for the post-concession maintenance. The costs associated with the post concession maintenance are shown in the figure. Similarly, when concession terms greater than 30-years are considered for analysis the public sector would start operating and maintaining the highway straightaway after the concession ends. This can be observed visually from the Figure 21.

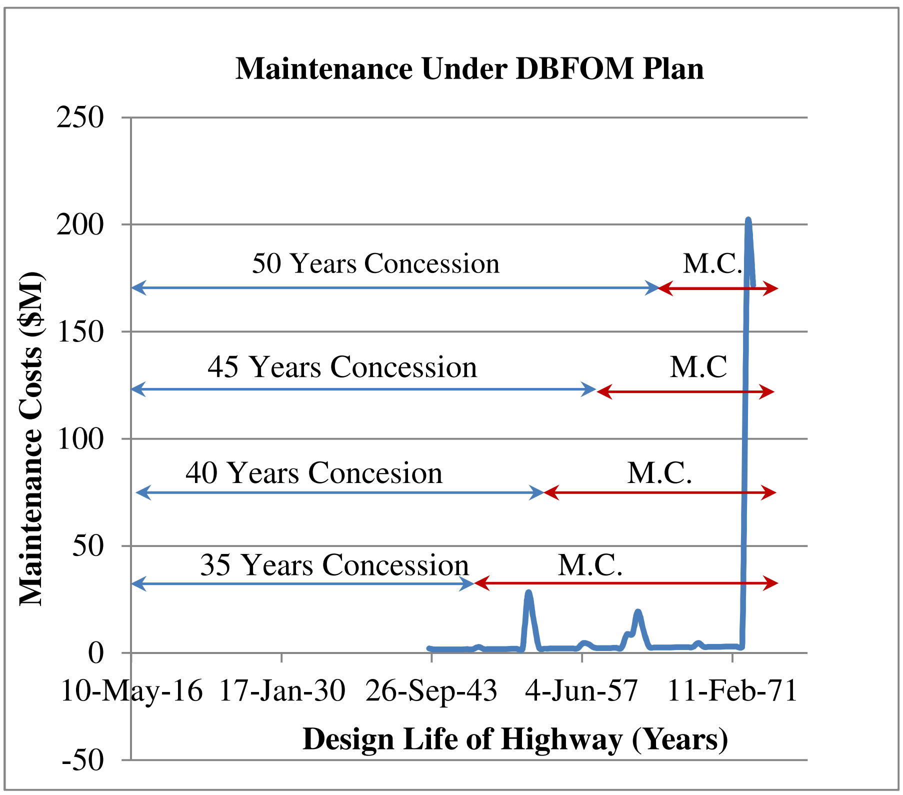


**Figure 21 Post Maintenace Costs With Different Concession Period**

Notice that if the concession period is increased by 5-years several small and high peaks (representing small and high maintenance costs respectively) can be avoided. On the other hand if the concession term is reduced the maintenance costs must begin immediately after the concession. For this analysis we considered concession period of 25-years which required combining the operating and maintenance costs from years 25 to 30 with the operating and maintenance costs beyond 30-years. For a better understanding this has been shown graphically in Figure 22.

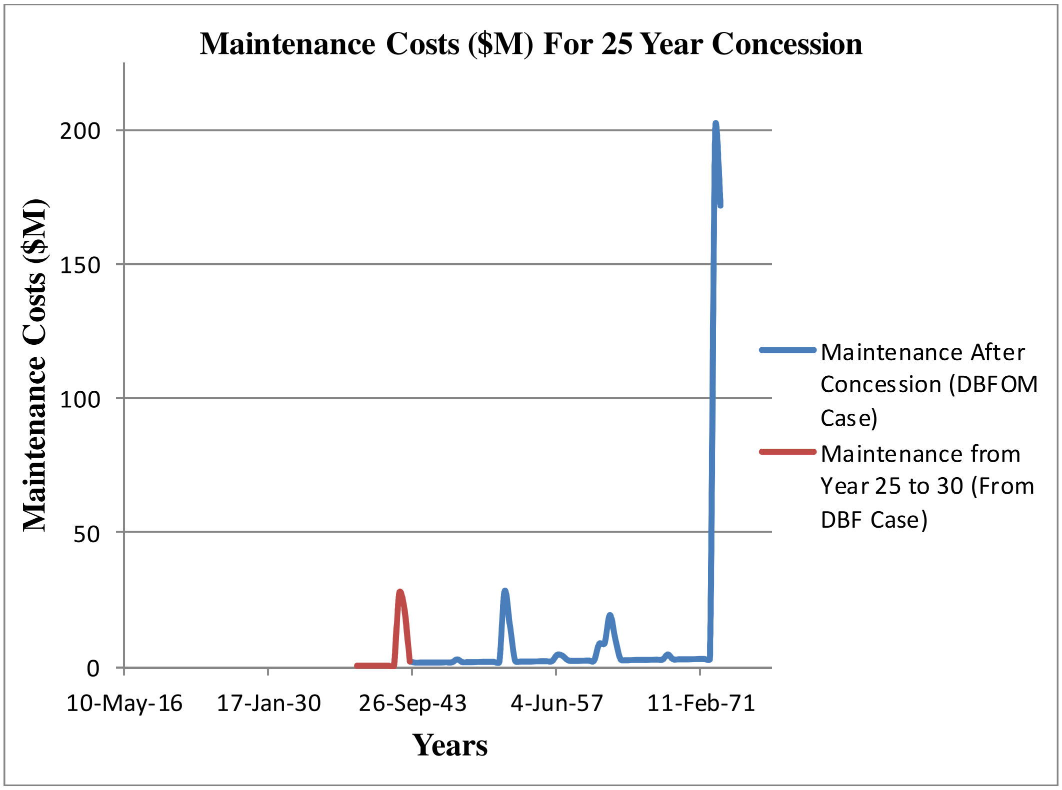


**Figure 22 Post Maintenance Costs (derived) For 25 Year Concession Period**

When the costs were obtained and grouped as shown in the above figures (Figures 20, 21 and 22) the post-concession costs as shown in Table 13 were obtained.

**Table 13 Post Concession Operation, Rehabilitation and Maintenance Costs ($M)**

| Description | Post Concession Operation, Rehabilitation and Maintenance Costs ($M) |
|---|---|
| 25 Concession Years | 644 |
| 30 Concession Years | 591 (Given) |
| 35 Concession Years | 572 |
| 40 Concession Years | 513 |
| 45 Concession Years | 486 |
| 50 Concession Years | 424 |

These post concession costs were used in our model as the fifth parameter of the model (as described in Section 4.2.9)

### 5.5 Setting Up Models With Different Concession Terms

The Multi-Objective Stochastic Dynamic Programming Model developed and used in this research work uses the Stochastic Dynamic Programming model framework with a Multi-Objective objective function. Hence the model is very much dependent on the Stages (years) and States (Private Sector's Financial State) of the project. On the other hand, the Stages and States are dependent on the concession term and must be changed according to the changes in concession period. Hence we must establish relationships between Stages and States for each concession term which requires us to develop equity cash flow statements (ECFS). While developing ECFS the overall process remains the same (as explained in Section 4.2.3) but the changes occur in the financial structure (especially repayment of bonds) due to increase or decrease of concession term. When the concession term is increased, the TIFIA repayment can be spread out to cover the concession term resulting in low payments throughout the concession terms resulting in higher NPV to the private sector. On the other hand if the concession term is decreased the TIFIA must be repaid within a shorter period of time which increases the amount of annual payments. This increases the annual cash outflows for the private sector resulting in reduced NPV. The effects from these changes are very much evident from figure 23 where all the cumulative cash flows for all the concession terms are compared.

Visually comparing the 20-years and 50-years graphs show that the overall models differ significantly. Also notice that the durations of both the cases are different creating overall differences in ECFSs. It must be noted here that the model uses the same annual costs for Operations as well as for Maintenance and Rehabilitation. These costs are same since these activities do not vary with the variation of concession term. For example, for a highway with concrete pavement the costs of Operation as well as Maintenance and Rehabilitation will remain unchanged for the private sector if the project is having a concession term of 25-years or 50-years.

The last thing that required due attention was including appropriate Tax Adjustments in ECFSs. The information about annual Tax Adjustments for 30-years as well as NPV of Tax Adjustments ($36M in the year 2009) was available from project documents. It was necessary to decide whether to use annual Tax Adjustment values or to use values derived from NPV of $36M (for the year 2009). It was noticed that if the actual yearly Tax Adjustments are used for analysis of 25 and 30-years' concession term then it would be necessary to use actual Tax Adjustments values to maintain consistency in analysis of concession terms more than 30-years. However, since the Tax Adjustment values beyond 30-years were not available from the project documents it was considered appropriate to use uniform payments derived from the NPV of Tax Adjustments for each and every analysis.

Similar process was adopted to develop ECFS for 35, 40, 45 and 50 years. In these ECFs the post-concession maintenance costs were shortened by 5, 10, 15 and 20 years respectively and the availability payments were lengthened by the same number of years. Thus we could obtain ECFS for 25, 35, 40, 45 and 50 years. The ECFs were used to calculate NPV from the project. This enabled us to estimate the allowable annual deductions that would allow the private sector to have an IRR of 11.5%.

Cumulative values of ECF were obtained which represented the Financial Upper Bound of the project. When the acceptable annual Deductions were applied to the ECFS the cumulative ECF gave the Financial Lower Bound of the project. All the Financial Upper and Lower Bounds obtained through this process are shown in figure 23.

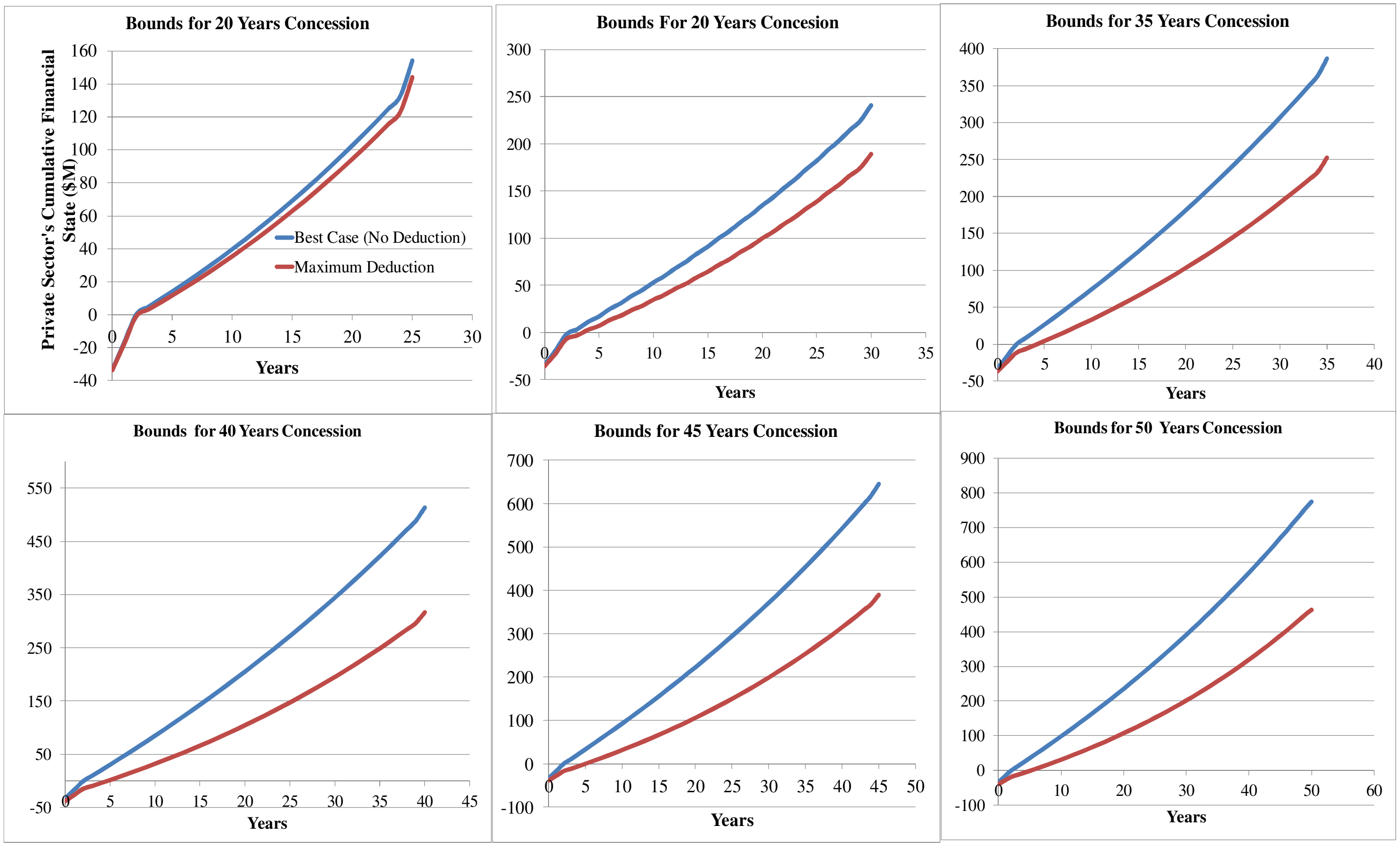


**Figure 23 Financial States and Stages For Different Concession Period**

It is evident from figure 23 that as the concession term (Stages) changes the Financial States (States) also changes. Furthermore, visual comparisons of allowable Financial States for projects with shorter and longer concession terms (say 25-years and 50-years) have significant differences. The differences are observed in the area enclosed by the financial bounds and range of Financial Status.

When projects have shorter concession terms the private sector will have to repay the TIFIA in a relatively shorter period of time. This increases annual TIFIA payment amounts and shrinks the values of ECFs. As a result the private sector's rate of return reduces indicating that the private sector has a very limited scope of earning above its MARR. In such conditions the private sector will only be able to bear very small deductions and if the deductions are higher, the private sector's rate of return might fall below the their MARR. Hence the Upper and Lower Financial Bounds are much closer when the concession term is shorter. [Note: When concession term was set to 20-years the NPV of ECFs was falling below the assumed MARR of 11.5%. Hence this option was not considered for analysis]

On the other hand when the concession term is higher the private sector has a very long-term to repay TIFIA which reduces the annual payment amounts. As a result the rate of return gets higher which allows the private sector to earn more. In these conditions the private sector can afford to have larger deductions and still manage to satisfy MARR. This is evident from figure 23. Notice that when the concession term is set to 50 years the

Financial Bounds are much apart indicating that the Private sector has a much broader range to earn.

The other difference was observed in the range of Financial Status. When the concession term was short the private sector had a shorter duration to perform and receive Availability Payments but when the concession term was long the private sector had longer duration to perform and receive Availability Payments. This difference is visible from the difference of range of Financial Status between the different graphs.

These differences were incorporated in the model and thus a model for each concession term was obtained. These models were run for 1000 iterations considering

1. Expected Deductions during backward-pass and random deduction during realization pass and
2. Random Deductions during backward-pass and random deduction during Realization Pass.

The analysis from the model output allowed calculating the overall life cycle cost of the PPP project with different concession term.

**5.6 Results**

The model was run 1000 times which gave us the frequency of occurrence of each MAP in the optimal solution. Using the number of occurrence as weights the average MAP for each concession term was obtained. This process was adopted for models using Expected

Values in backward-pass as well as the models using random values in backward-pass. The results obtained from the analysis are shown in the following table.

**Table 14 Comparison Of Results (MAPs)**

| Description | Average Design MAP ($M) | |
|---|---|---|
| | MODDP Model | MO$\tilde{S}$DP Model |
| 25 Concession Years | 35.3562 | 35.3566 |
| 30 Concession Years | 34.676 | 34.698 |
| 35 Concession Years | 33.099 | 33.121 |
| 40 Concession Years | 31.7388 | 31.7478 |
| 45 Concession Years | 30.5457 | 30.6129 |
| 50 Concession Years | 29.8912 | 29.9029 |

It is evident from the above table that as the concession term is increasing the average MAPs are decreasing. These decreased values of MAPs compensate towards the increased concession term and optimally satisfies the public and private sector objectives. As per the results, if the public sector can afford $29.9M as MAPs they must consider a concession term of 50-years. On the other hand if the public sector can afford MAPs up to $35.356M they can consider awarding concession period of 25-years. The results can be summarized through Operation Period vs Availability Payment plot as shown in figure 24.

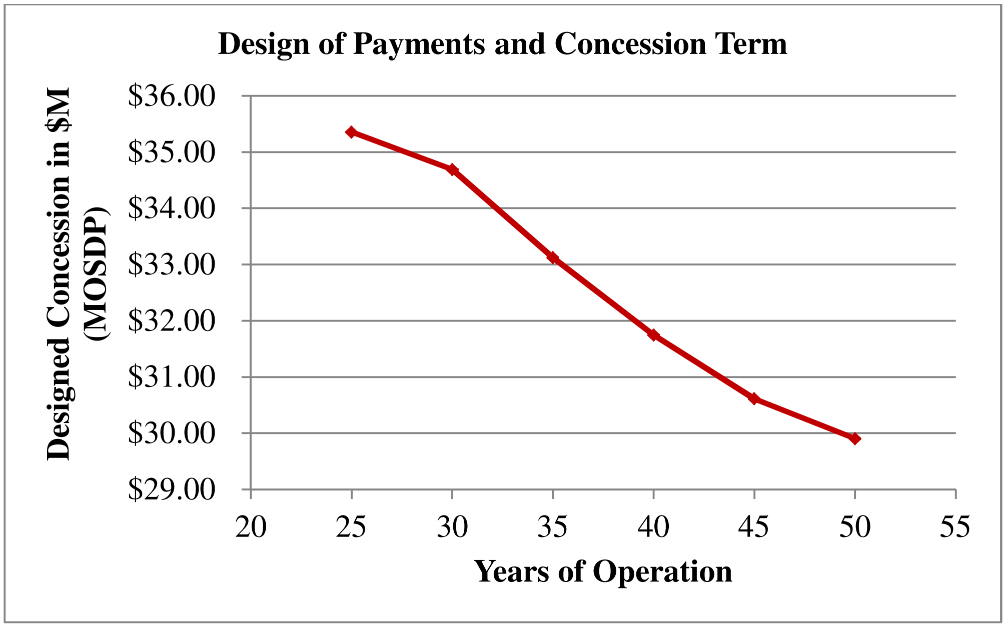


**Figure 24 Availability Payment Design for Presidio Parkway Project**

Thus, using the above model the private sector can design MAPs and concession duration simultaneously. The solutions obtained from this research ensure that while the private sector realizes its MARR, the public sector's objective of reducing the public sector costs is also met.

# Chapter 6 Availability Payment Design – Analysis of Factors and Parameters

## 6.1 Factors Affecting Availability Payment PPP Designs

In the previous chapters, MAPs and concession durations were designed for the Presidio Parkway Project using the hybrid models. The model is capable of integrating concessionaire's several characteristics in the design. The model can thus be used to design contracts suitable for concessionaires with different characteristics.  This makes the hybrid model highly sophisticated and can provide us valuable insights about Availability Payment PPP designs under uncertainty and variations of several important factors. For example, before bidding, the concessionaire is unknown and hence it is safer to expect a mediocre performance during the concession term. The mediocre performance could lead to very high deductions, increasing the risk of a concessionaire abandoning the project. The MO$\tilde{S}$DP model can be set to take deductions corresponding to mediocre performance (as well as for good performance) as inputs and design of a conservative MAP. This approach would help the public sector hedge the risks from the event where a concessionaire gets into a partnership but cannot deliver the services as expected, thus getting heavily penalized and eventually abandoning the partnership. On the other hand, after bidding, the concessionaire is known to the public sector and it can use the bid documents to estimate concessionaire's performance and design suitable MAPs. Furthermore, due to uncertainty, the factors that influence may not remain same throughout the concession term. This could also lead to situations that would not be in public and private sector interests. Hence, this current chapter is devoted to identifying the factors that can influence the overall design as well as determine the extent to which these factors influence the design of Availability Payment PPPs.

The factors considered for analysis are:

1. Private sector's performance risks
2. Private sector's risk aptitude – case of optimistic and risk-taking private sector
3. Private sector's efficiency during construction
4. Improvement in private sector's O&M efficiency.

## 6.2 Effect of Private Sector's Performance Risks on MAPs

Availability Payment PPPs are long-term contracts usually spanning 20 to 30 years. During these years the concessionaire performs its duties (i.e., keep the highways available for use) and in return gets annually reimbursed through predetermined Availability Payments. The reimbursement is 100% for full availability of the highway lanes, but if the highway is closed due to any reason, the penalties are imposed and the payments are reduced accordingly. The deductions (from penalties) are not only dependent on concessionaire's performance efficiency but they are also dependent on all the uncertainties associated with long-term projects.

For a highly efficient private sector, these deductions can be expected to be much less, but if unexpected uncertain events occur (for example, the concessionaire's subcontractor is forced to file bankruptcy and abandons the project or the region faces unexpectedly high fog in the region due to environmental imbalance along the alignment of the highway), then there are all chances that the concessionaire could face heavy penalties. The situation would be much grimmer for the concessionaire with mediocre performance efficiency. Under these uncertain conditions, it is necessary that the MAPs are designed to protect the project from concessionaire's performance uncertainties.

The control points (discussed in Sections 3.5 and 4.2.1.3) enable us to integrate the concessionaire's performance under uncertainty into our analysis. Let us assume that a concessionaire is evaluated on the basis of five different attributes. These attributes can be selected by the public sector to identify the best suitable concessionaire for a given project: for example, attributes like cost overruns, schedule slippage, accidents, experience in operating and maintaining highways, number of permanent employees with relevant experience, financial stability, financial liquidity or any other similar attribute. Once these attributes are obtained (or estimated) for the concessionaire, the public sector can establish a control point corresponding to the concessionaire's overall attribute score. For example if the concessionaire gets a combined attribute score of 90%, then we can put the control points at 10% from the lower financial boundary (discussed in Section 3.6) towards the upper financial boundary indicating that the concessionaire would only require a 10% increase beyond the lower financial boundary to manage the project. Similarly, if the private sector gets a combined attribute score of 70%, then the control points can be located at 30% from the lower financial boundary. Thus, we can say that if the efficiency is expected to be high, then the control point can be set near the lower boundary and thus these control points can be very effectively used to represent concessionaire's performance efficiency.

Once the control points are obtained and set up in the model, the model would use them to achieve desired financial levels for the concessionaire. The control points for an efficient concessionaire would be set near the lower financial boundary and direct the model to measure the financial variation from near the lower bound (since the control points are set near the lower boundary). Hence, the designed MAPs would be very low. On the other hand, if the private sector efficiency is expected to be low, the control points would be obtained towards the upper boundary (discussed in Section 3.6), which would enable the models to reduce the costs but since the control points would be towards the upper boundary, the resulting MAPs could be higher. Thus, the position of control points can help to design MAPs suitable for a particular concessionaire. Once these specific design MAPs are obtained, the public sector can use them during negotiation with the concessionaire. In this section, we focus on determining MAPs that could be used during negotiations while not knowing about private sector's O&M efficiency.

To accomplish this task, control points were set up to reflect the private sector's O&M Efficiency. As discussed above, the control points were set up near the lower boundary when the private sector's O&M efficiency was expected to be higher. By joining all such control points, we obtained a boundary, which has been named the control bound. Similarly, control bounds were also obtained that would represent concessionaires with different O&M efficiency. Notice that in Figure 25, several bounds were setup between the upper and lower financial bounds, each representing a concessionaire with a different O&M efficiency. Thus, after this analysis we would be able to design MAPs that can be used for negotiations with concessionaires with some level of efficiency.

Figure 25 shows the control bounds used during the analysis. In this analysis, it was assumed that the private parties that would qualify for the partnership would have excellent, extremely good, very good, good, above average or at least average O&M efficiencies. For each of these efficiencies, specific control points were obtained and used to design MAPs. For excellent O&M efficiency, the control points were set up as the lower bound itself; for average O&M efficiency, the control points were set up as the upper bound itself. Control points for all other efficiencies were set up between the upper and lower limit.

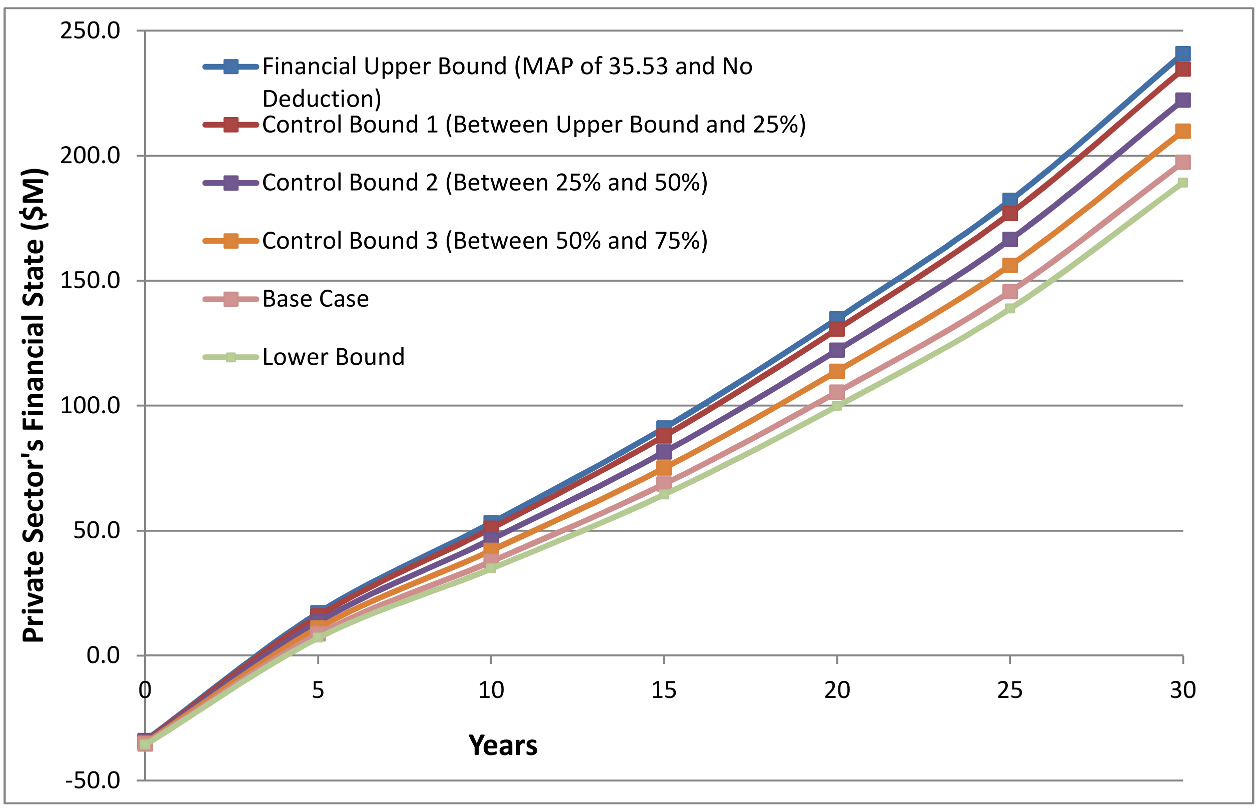


**Figure 25 Setting Up Control Bounds and Decision Variable Paths**

The base case analysis assumed that the concessionaire would have very good efficiency, and hence the control points were set up between the upper and lower boundaries in the lower one-fourth region. Similarly, the control points for concessionaires with very good, good and above average O&M efficiencies were set up between the half and three-fourth region; one-fourth and half region; and upper one-fourth region, respectively. The model was to be run 97 times with randomly generated deductions to ensure 95% confidence interval within 10% error (Appendix 12). However, for this analysis the model was run 1,000 times and following results were obtained.

**Table 15 Comparison of Designed MAPs**

| Description | Average Design MAP ($M) | |
|---|---|---|
| | MODDP Model | MO$\tilde{S}$DP Model |
| Control Bound as Upper Bound | 34.703 | 34.747 |
| Control Bound Between Upper Bound and 25% | 34.719 | 34.7315 |
| Control Bound Between 25% and 50% | 34.709 | 34.725 |
| Control Bound Between 50% and 75% | 34.7018 | 34.719 |
| Control Bound as Lower Bound | 34.645 | 34.644 |
| Base Case | 34.676 | 34.689 |

Table 15 shows that when the private sector was expected to perform at extremely high efficiencies (i.e., control points were set on the lower boundary) the MAPs could be reduced from $35.53M to $34.644M, a reduction of 2.494% in MAPs. On the other hand, if the private sector's O&M efficiency is totally unknown, the public sector can still reduce the MAPs from $35.53M to $34.747M, which converts to a 2.204% reduction in MAPs. In terms of position of control point, notice that designed MAP values decrease as the control points move nearer to the lower boundary. The control points near the lower boundary represent higher efficiency. It can be observed that a 1% change in the position of control bound could change the MAPs by $0.0089M.

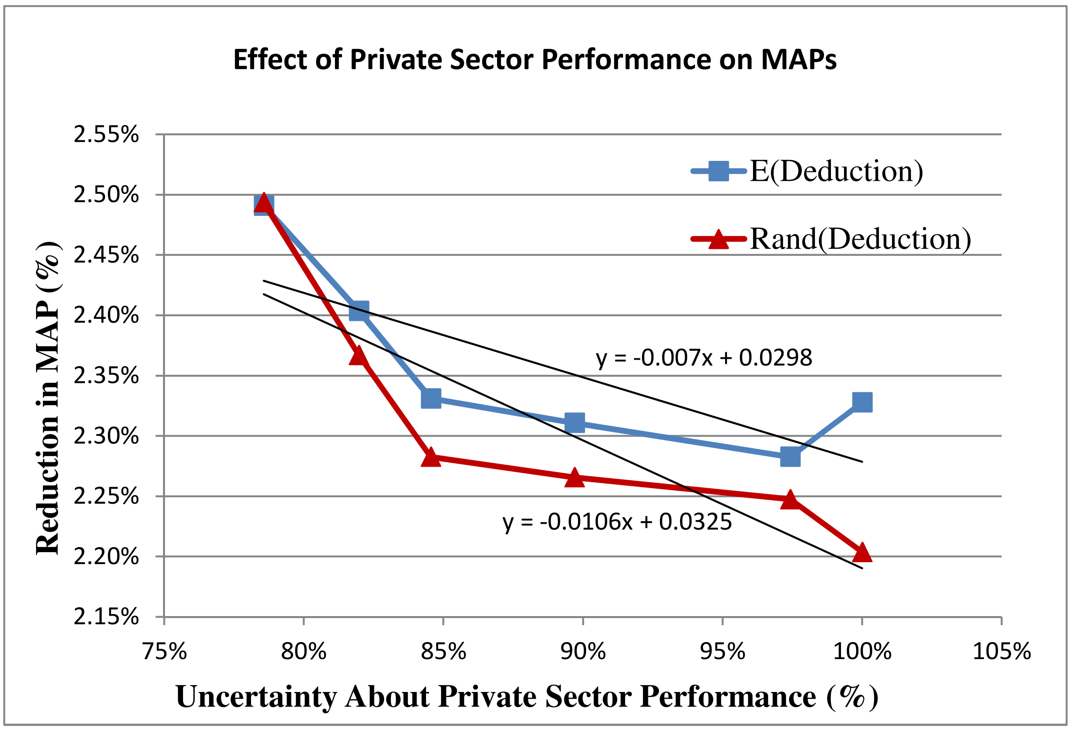


**Figure 26 Variation of MAPs with Variation in Control Bounds**

It can be observed that both the plots follow a decreasing trend. The decreasing trend reflects the effect of control points (i.e., private sector's O&M efficiency) on the overall decision (MAPs) as expected.

Summary statistics (from Table 14) reveal that when MODDP is used during the backward-pass, the average design MAP is \$34.692M, and when MO$\tilde{S}$DP is used during backward as well as realization passes, the average design MAP is \$34.709 M. The standard deviations are 0.027 and 0.037, respectively.

### 6.3 Discussion - Effect of Private Sector's Performance Risks on MAPs

The control points described in the preceding section leads us to negotiable MAPs when the private sector's O&M efficiency might be unknown. When the public sector knows that the private sector would be very efficient, it can design an aggressively smaller MAP by setting control points closer to the lower financial boundary. Similarly, if the O&M efficiency is unknown, control points can be up accordingly to design MAPs. It is evident from Figure 26 that as the private sector performance uncertainty decreases, the Design MAPs also reduces. The trend-line for the graph shows a relationship between public sector's desire to reduce costs and Design MAPs. Thus, we can conclude here that control points influence MAP designs and can help the public sector reduce the overall cost of the project. Also, notice that since the MOSDP model is developed as a multi-objective optimization model, the objective that provides stability to the private sector's financial state (project finance) does not allow extreme reduction of MAPs, thus reducing private sector's risks of financial failure.

As the use of performance-based PPPs is expected to increase (Parker, 2011) using the MODDP and MO$\tilde{S}$DP models with appropriately set control points can be extremely useful. For example, in case of the Presidio Parkway Project, the private sector will be responsible for several tasks including operating and maintaining the tunnel systems as well as intelligent transportation systems (ITS) and communications. These tasks are highly specialized and might not be the strengths of the private sector. In such cases, the control points can be set to reflect the private sector's weaknesses and the Design MAPs will be higher than expected. This will happen since the models would read the private sector's weaknesses from the control points and would design MAPs that would enable the private sector cope with the reduced MAPs in case of defaults. If these Design MAPs turn out to be very big, the public sector can consider retaining the responsibilities with itself.

Thus, the public sector can very effectively use the MODDP and MO$\tilde{S}$DP models with appropriately set control points to design Availability Payment PPPs. This would help them to achieve the DOT's long-term performance goals. Although the analysis of Presidio Parkway Project shows that the designs would be influenced by private sector's performance efficiency, the effect was not significant.

### 6.4 Private Sector's Risk Aptitude

The private sector is known for their risk-taking characteristics. It is not difficult to find a private party that would continue working on a project even after earning returns less than the expected returns. This approach is very likely for long-term projects like PPPs. It is assumed here that the private sector experiences losses and as a result the private sector would earn less than its MARR. Graphically, we can say that the private sector finds its financial state below the lower financial boundary (Figure 5) indicating that the private sector gets returns below its MARR level. In a strict sense, the private sector must quit but the private sector's risk-taking attitude may enable it to continue as a partner.

The risk-taking behavior of a private party would keep it motivated to continue on less profitable projects. A private party with a relatively higher risk-taking attitude would always be motivated to work on projects yielding relatively lower MARR when compared to private parties with relatively lower risk-taking attitude. If such a high risk-taking private party is expected to win the bid, the public sector can capitalize on private sector's risk-taking behavior. In this section, we use the MODDP and MO$\tilde{S}$DP model to enable the public sector to design MAPs, depending on private sector's risk aptitude.

This scenario was modeled by using the method discussed in Chapter 3 and 4. The only modification to the model is in its additional bound, which has been named as the Optimistic Bound. This bound was developed by assuming that the private sector would continue working as a partner even if the actual MARR falls down below the expected MARR. The scenarios assumed that the private sector realizes returns at 8%, 9%, 10%, 11%, 12% and 13%. Figure 27 shows (from top to bottom) the upper financial bound (i.e., public sector interests); dotted control points for 11.5% (i.e., representative of private sector performance) and dotted lower boundary for 11.5% (representing private sector interests); and control points for 10% return and lower boundary for 10% return.

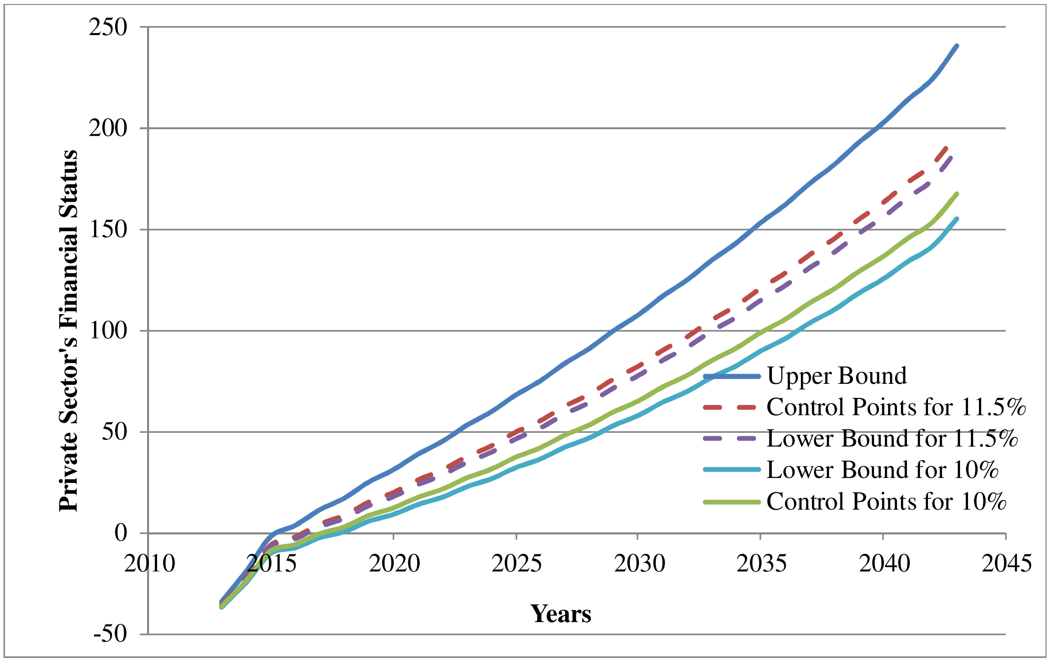


**Figure 27 Bounds Representing Optimistic Private Sector**

For this analysis, 97 iterations were run and the results were obtained as shown in table 15.

**Table 16 Comparison of Designed MAPs**

| Private IRR | Average Design MAP ($M) | |
|---|---|---|
| | MODDP Model | MO$\tilde{S}$DP Model |
| 8% | 33.449 | 33.472 |
| 9% | 33.778 | 33.745 |
| 10% | 34.132 | 34.164 |
| 11% | 34.531 | 34.516 |
| 11.5% (Base case) | 34.676 | 34.689 |
| 12% | 34.851 | 34.834 |
| 13% | 35.233 | 35.243 |

Plotting these values in a graph (Figure 28) we observe that the rate of return is negatively correlated with Design MAPs. We can also observe that as the risk-taking aptitude increases (i.e., acceptable rate of return is decreasing), the design MAPs decrease. Analysis shows that for a 1% reduction in private sectors' acceptable rates of return, the public sector can reduce the MAPs up to $0.354M.

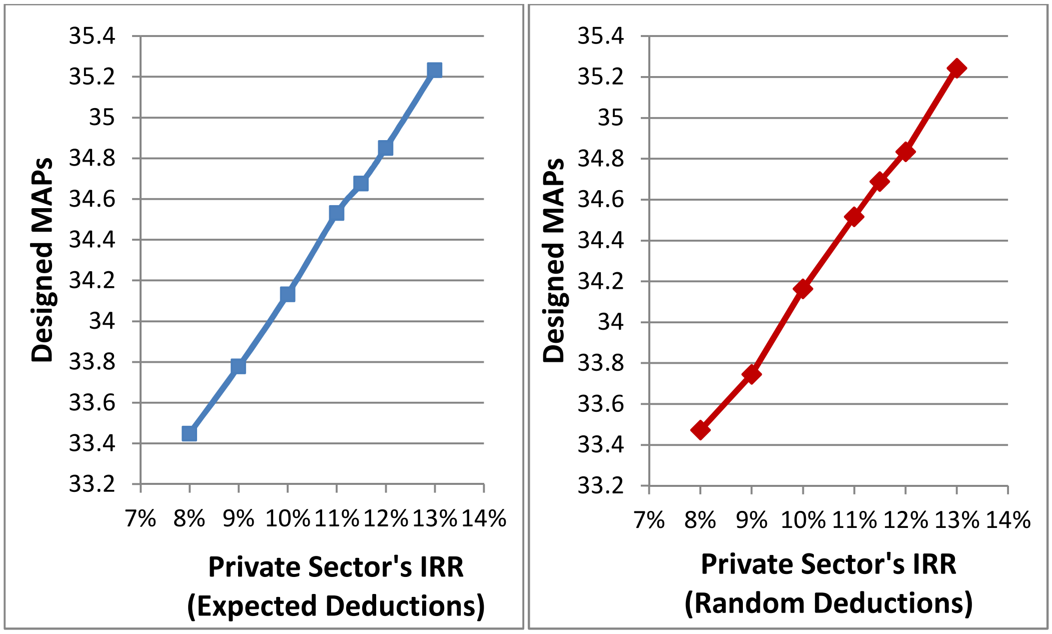


**Figure 28 Relation between Private Sector's Risk Aptitude (MARR) and MAPs**

### 6.5 Discussion - Private sector's risk aptitude

This scenario represents a case where a private party is willing to continue in a PPP project even though it experiences some losses. In strict terms, the private party must quit; however, in certain conditions it may not quit. If the loss is realized during the initial years of operation, it is rational to expect the private party to be optimistic (due to its risk-taking approach) about recovery during the remaining years of operation. Conversely, if the loss is realized towards the end of concession, it is again rational to expect that the private party would still continue with the project for two reasons. First, the private party would want to finish the project just to avoid earning a reputation of quitters and, second, the time value of money would reduce significantly after 20-30 years. In either case, the private party would consider completing the project. Apart from this, when a new private party enters the PPP market, it would willingly take additional risks (even by reducing profits) to learn and establish themselves in PPP markets. The analysis conducted in the previous section shows that if the private sector is known to be risk-taking, then the public sector can reduce MAPs.

The MODDP and MO$\tilde{S}$DP models have been used to design MAPs that would enable the public sector to reduce the overall expenses when the private sector is expected to absorb reduction in returns. This would enable the public sector to offer MAP limits that would be much smaller. Thus, this approach would enable the public sector to protect public interests.

### 6.6 Private Sector's Efficiency During Construction

In the previous chapter, it was assumed that the private sector's construction efficiency enabled them to earn 3% profit. However, the private party is not known until the bidding ends. Hence, the public sector does not know anything about the private sector's construction efficiency. If a private party with high construction efficiency wins the bid, then they would be able to earn profits as expected (around 3%), but if the private party is less efficient, then the profit levels could reduce. This scenario focuses on the later situation and designs MAPs such that the risks from private sector's unknown construction efficiency can be hedged off. This analysis is conducted by assuming that the ability of earning profits is directly correlated with the private party's construction efficiency.

Let us assume that the private sector's efficiency is about half of what is required and thus manages to earn only 1.5% of $501M, thus reducing the profit by $7.515M. Due to this, the private sector enters the operation phase at a negative state of $42.485M instead of $35.716M.

Under these circumstances the private sector may abandon the PPP project, which could go against the overall objective of project. Hence, in such a condition, the public sector must adjust MAPs to ward off the risk of private party abandoning the project by allowing the private party to cope with the reduced profits. At the same time, the public sector must also protect the public interests by offering just appropriate amounts of MAPs. To enable the public sector to design such MAPs, the base case analysis was used again. The base case was used here so that a reasonable comparison could be made between the results obtained from the base case and the current scenario.

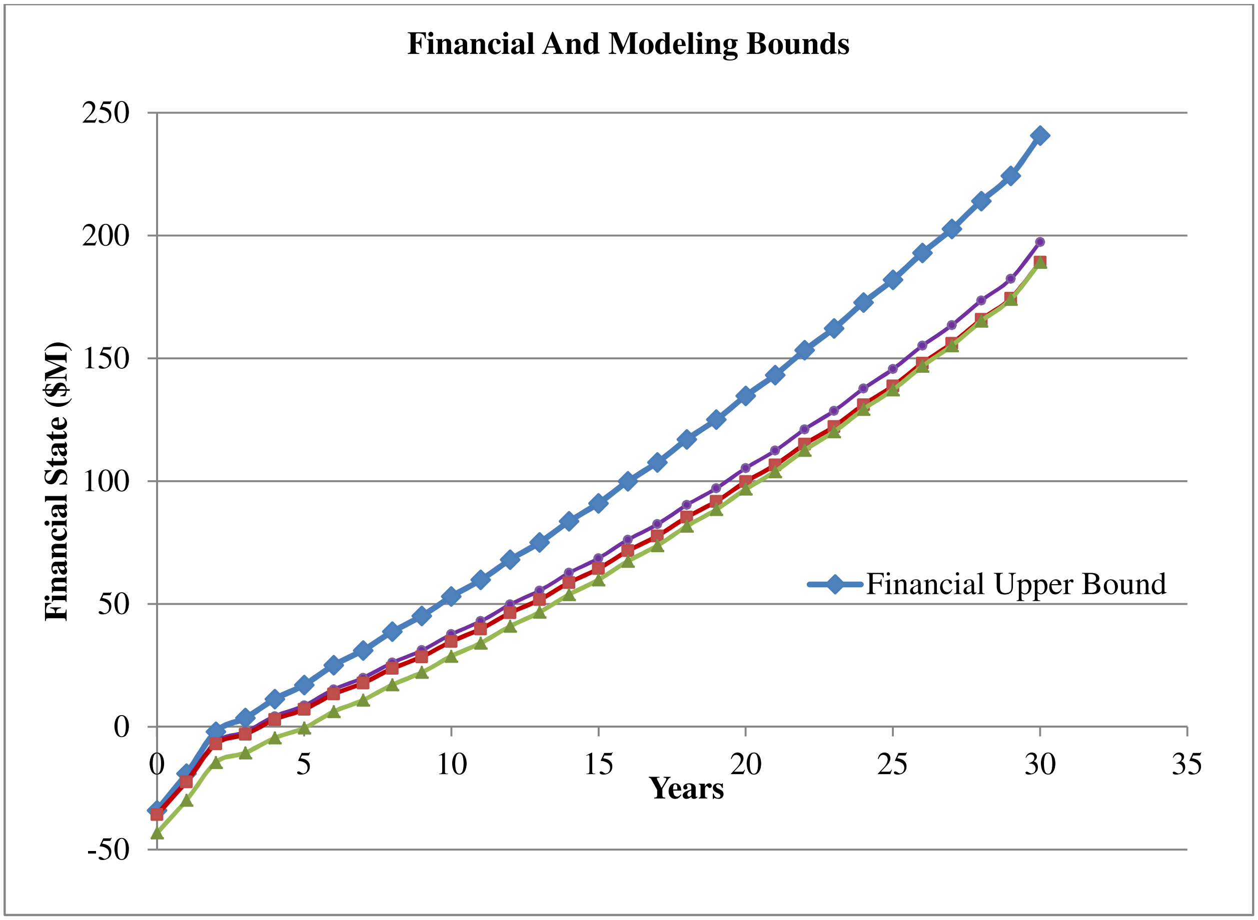


**Figure 29 Bounds Representing Private Sector's Loss During Construction**

In the base case model, the lower bound represents the MARR bound. The private sector would abandon the project if its performance was substandard, leading to deductions. This would reduce their profits, and thus their financial status goes below the lowest bound (MARR bound). But, in the current scenario, we wish to design MAPs that would allow the private sector to cover-up the lost money. Hence, the model was set up with a new bound that was below the project’s MARR bound. This new bound gradually merges with the MARR bound at the end of concession period and has been shown in Figure 29. The second bound from below represents the MARR bound for the private sector and the lowest bound includes states that fall below the MARR level when the private sector experiences loss. It is evident from the graph that during the initial years of operations, there is a considerable difference between the two bounds. However, as the years pass by, the difference decreases and as the project reaches the end of concession period, the two bounds merge together. All other parameters of the model have been kept the same as they were in the base case. This would represent a scenario where the private sector's efficiency was half. Similar scenarios were developed and the models were set up for 0%, 0.5%, 1.0%, 1.5%, 2.0% and 2.5% profits apart from the base case scenario where the profit was set up to 3.0%.

These models were run 97 times using values of expected deductions during the backward-pass and random deductions during the realization pass. The observations of iterations showed that when the efficiencies were less (i.e., the profit levels were less), the private sector's financial condition fell below the lower boundary several times, which means that the private sector quit. For example, when the iterations were run for 1.5% profit scenario (using expected deductions during backward-pass), the 73$^{rd}$ iteration that did not complete as the financial state was below the lower boundary. Similarly, when values of randomly generated deductions were used during backward and realization pass the 19$^{th}$ and 23$^{rd}$ iterations did not complete. Similar observations were increasingly observed when iterations were carried out for profit levels less than 1.5%. The analysis was carried out for all the profit levels and following results were obtained:

**Table 17 Design of MAP Values Considering Various Construction Efficiencies**

| Profit in % of Construction Cost | Average Design MAP ($M) | |
|---|---|---|
| | MODDP Model | MO$\tilde{S}$DP Model |
| 0.0% | 35.206 | 35.205 |
| 0.5% | 35.150 | 35.156 |
| 1.0% | 35.053 | 35.085 |
| 1.5% | 34.991 | 34.988 |
| 2.0% | 34.932 | 34.914 |
| 2.5% | 34.799 | 34.793 |
| 3% (Base Case) | 34.676 | 34.689 |

The analysis shows that as the profit levels vary from 0% to 3% the MAPs vary from $35.206M to $34.676M. Thus, we can say that for the Presidio Parkway Project, variation of profit by 1% would create a difference of $0.177M on MAPs.

Also note that for the worst case scenario where the private sector does not make any money from construction activities, the public sector can offer limiting MAPs of $35.205M, which is $0.325M less than the limiting MAP of $35.53M offered for the Presidio Parkway Project. These savings adds up to $9.75M for the concession period of 30-years. On the other hand, if the private sector is expected to be very efficient and if the private sector can earn a profit of about 3% (as expected), then the appropriate MAPs would be $34.689M, which is $0.841M less than the limiting MAP of $35.53M. This would enable the public sector to save $25.23M during the whole concession period.

### 6.7 Discussion About the Private Sector's Efficiency During Construction

The private sector's construction efficiency can have a significant effect on MAP design. If the efficiency is high, they will perform well and thus meet all the contractual obligations. Such a situation would be an ideal situation where the private party would continue working on the project and this would also be beneficial for the public sector. However, the public sector does not know anything about the private sector's construction efficiency when issuing project tender. If the limiting MAPs are higher than required, then it would prove to be costlier and thus against the public interests. Conversely, if the limiting MAPs are lower than necessary, the competition can be low and the private sector might abandon the project that would again go against the public interests. Hence, when issuing the tender, the limiting MAPs must be designed incorporating uncertainties in private sector's construction efficiency.

During the scenario analysis in the previous section it was assumed that a private party's profit making capability is directly correlated with its construction efficiency. Higher construction efficiency would enable a private party to earn profits as per its expectations and vice versa. Hence, the variation of profit levels in the previous section represented a variation of the private sector's construction efficiency. The results show that as the profit levels were reduced, the design MAP values increased. This implies that if the private sector's construction efficiency is expected to be less, then the MAPs must have higher values to ward off the risks of the private sector, abandoning the project midway.

### 6.8 Improvement in Operation Efficiency

PPPs are long-term projects. The length of the project allows the private sector to monitor and improve its performance over the length of the O&M phase. The improvement can lead to higher efficiency during the operations phase, leading to lower deductions. This scenario presents the analysis considering that the private sector improves continuously during the concession period leading to lower deductions towards the end of concession period and thus earning higher profits.

The base-case model described in Chapter 4 was used here again for this scenario, where the deductions were assumed to be associated with private sector inefficiency. Deductions were assumed to follow discrete uniform distribution throughout the O&M phase. But, if the private sector improves its efficiency, then the deduction parameters would change during each stage. In order to estimate the deductions after improved performance, the concept of learning curves was used.

Mathematically learning relationship can be expressed as (Mantel et al., 2007)

$$T_n = T_1 \bullet n^r \qquad (6.1)$$

where, $T_n$ = Time required to complete the nth unit

$T_1$= Time required to complete the first unit and

r = Exponent of learning curve and can be calculated as

r = log(learning rate)/log(2)

The above learning curve relationship focuses on the time of completion of a task. It is known that when a task is repeated several times, the time required to complete the task would reduce. The above equation calculates the time required to complete the task nth time, considering that during each repetition, the efficiency to complete the task increases which in turn reduces the time. Along the same line, it has been assumed here that as the private sector continues to operate the asset, its O&M efficiency improves and gradually reduces the deductions. Since the two processes have similarities, the concept of the learning curve has been used to estimate deductions considering private party's learning during the operation phase.

**Table 18 Gradual Learning (10%) Leading To Decrease in Deductions**

| Year | Deduction | Year | Deduction | Year | Deduction | Year | Deduction |
|---|---|---|---|---|---|---|---|
| 2014 | 1.66456 | 2022 | 1.19193 | 2030 | 1.0821 | 2038 | 1.02049 |
| 2015 | 1.49811 | 2023 | 1.173 | 2031 | 1.07274 | 2039 | 1.01442 |
| 2016 | 1.40856 | 2024 | 1.15613 | 2032 | 1.06396 | 2040 | 1.00862 |
| 2017 | 1.3483 | 2025 | 1.14094 | 2033 | 1.0557 | 2041 | 1.00306 |
| 2018 | 1.30333 | 2026 | 1.12714 | 2034 | 1.0479 | 2042 | 0.99773 |
| 2019 | 1.26771 | 2027 | 1.11451 | 2035 | 1.04051 | 2043 | 0.9926 |
| 2020 | 1.23835 | 2028 | 1.10289 | 2036 | 1.03351 | | |
| 2021 | 1.21347 | 2029 | 1.09212 | 2037 | 1.02684 | | |

When formula (6.1) is applied to the project data considering a learning rate of 10%, we observe a gradual decrease in deductions. The gradual decrease in deductions can be observed from table 17. Using the decreasing values of deduction, the base case model was run 97 times. Similar calculations were also carried out for 5%, 15% and 20%.. This gave us the following results.

**Table 19 Comparison of Designed MAP Values**

| Learning | Average Design MAP ($M) | |
|---|---|---|
| | MODDP Model | MO$\tilde{S}$DP Model |
| 0% (Base Case) | 34.677 | 34.689 |
| 5% | 34.546 | 34.584 |
| 10% | 34.466 | 34.460 |
| 15% | 34.375 | 34.387 |
| 20% | 34.298 | 34.305 |

It is evident from Table 18 that since the private sector is able to decrease the deductions the public sector can consider reducing the MAPs. From the above results, we can say that a 1% increase in learning would allow the public sector to reduce the MAPs by $0.019M.

## 6.9 Discussion - Improvement in Operation Efficiency

The private sector is generally more resourceful and experienced than public sector in terms of construction, maintenance and operations of assets which enable them to control the project efficiently. This allows them to gradually improve the project performance and also to reduce deductions. Apart from this, the private sector is known to use various Project Maturity Models that help them improve their efficiencies on repetitive works. Furthermore, the private sector can get an advantage of economies of scale, enabling them to be more economical. Hence, it is reasonable to assume that the private sector will become more efficient with the passage of time.

This could mean that the private sector would be able to make profits more than expected and could lead to concerns from some sections of the society. To avoid this, the analysis in the previous section was focused on designing MAPs that could offset the extra profit earned towards the end of concession period.

Analysis was conducted by gradually reducing the deductions by considering gradual improvement in the processes. The concept of the learning curve was used to estimate the gradual reduction in deductions. The analysis was conducted considering different learning rates that enabled estimating corresponding deductions. Analysis results show that as the deductions are decreasing (because of gradual improvement) the design values of MAPs are also decreasing. However, for this case study, it was observed that the effect of the private party's gradual improvement has a limited effect on MAPs. In addition, if the Time Value of Money principles are applied, the overall savings from MAPs would shrink further. Hence, we conclude here that private sector's improvement in O&M does not significantly affect the MAP design.

### 6.10 Chapter Summary

This chapter focuses on identification and quantification of factors that can affect the design of Availability Payment PPPs. Four factors were analyzed in this chapter viz: private sector's performance uncertainty, private sector's risk aptitude, private sector's construction efficiency and gradual improvement in private sector's O&M efficiency. The analysis shows that the private sector's risk aptitude and the private sector's construction efficiency are significantly affected the MAPs, while the private sector's performance uncertainty and improvement in private sector's O&M efficiency had limited effect on MAP design for the Presidio Parkway Project.

# Chapter 7 Summary and Conclusion

## 7.1 Overall Summary

The literature review of PPP practices around the world enabled identifying the problems in PPPs and defining the boundary of this research work. This work, for the first time, combines planning, construction, operations and maintenance and post-concession project costs in a single model for designing Availability Payments. This work thus helps in obtaining solutions considering the entire PPP project, rather than only one or two phases of the project.

The model developed during this research is unique, since it aims to satisfy competing objectives simultaneously. The model designs MAPs that ensure public sector cost reduction as well as reduce a PPP project's financial variation. The model also helps identify the most economical concession term. The analysis also helps to identify and measure the effect of various factors on the design of Availability Payment PPPs.

## 7.2 Contribution to the Body of Knowledge

This research work has four major contributions to the body of knowledge.

1. The Design of Availability Payment PPPs

This research work provides a method to design Availability Payment PPPs. Currently, the public sectors around the world do not have any tools to design Availability Payment PPPs. They largely rely on the private sector's estimate of availability payments. The method developed in this research work can be used to design MAPs as well as concession period. The method used in this research work provides designs leading to win-win conditions for the public and private parties, since the solutions ensure that the public sector costs are reduced and the financial variations are reduced simultaneously. This research work establishes a method that enables inclusion of uncertainties about the private sector into the designs, thus making the Availability Payment PPPs more stable and reliable. Thus, this research establishes a rigorous approach for designing PPPs that would ensure public interests.

2. Identification and Quantification of Factors Affecting Designs

This research puts forward an approach to identifying and quantifying the factors that can affect the Availability Payment designs. The factors analyzed during this research work were private sector's performance, private sector's risk aptitude, private sector's construction efficiency and improvement in private sector's O&M efficiency. Three amongst these four factors are related to private sector's performance and hence this research work can be used to design performance-based Availability Payment PPPs rather than designing finance based Availability Payment PPPs. Thus, this research work can help the public sectors achieve the long-term performance-based objectives.

3. A Model Capable of Integrating Various Project Phases in Design

In this research work, a hybrid model was developed to design Availability Payment PPPs. The model was developed by combining a stochastic dynamic programming model with a multi-objective linear programming model. This model enables integration of: dynamic conditions arising during the concession term; performance uncertainties spread over the concession period;

and simultaneous consideration of public and private objectives as well as inclusion of post concession O&M costs. Thus, this research provides a model that can integrate several phases together and provide a design that would address all issues arising in these phases.

4. Extended Use to Other Long-term PPP Projects

The model developed and discussed in this research work basically uses inputs from projects' equity cash flow statements. This makes the model more versatile for other performance-based long-term PPP projects. The model can be modified and used for designing PPP tenders and also for negotiations after bidding. For example, the model can be used to design shadow toll PPPs after replacement of deductions by traffic throughput and MAPs by shadow tolls.

### 7.3 Limitations and Future Works

The results obtained from the analysis were convincing as well as reasonable. However, the results can be improved by overcoming the limitations faced during this research work. These limitations and plans to overcome them are listed below:

1. The Control Financial States (CFS) used in this research work were placed between the upper and lower financial bounds by judgments. However, the locations of these CFSs can be linked with several screening and performance criteria including, but not limited to, concessionaire's experience, financial stability, market reputation, safety, lane availability, highway through put and passenger comfort. Hence if the concessionaire is expected to do poorly on these criteria, the CFS can be designed and used to reflect such a concessionaire in the model. This would enable the decision-makers to set up the model

specifically for a particular concessionaire and use it to design MAPs and concession term.

2. The model developed above can be improved by introducing a penalty function. Using the penalty function the model can be forced for selection of a single MAP throughout the concession. However, the contractual penalty amounts that may be associated with making contractual changes are not available. These costs are generally categorized as transactional costs and consist of several contractual fees.

3. The model developed and used in this research work has a stochastic dynamic programming model's framework. Hence, increasing the stages and states will significantly increase the computational time. Hence, several values were rounded off to reduce the computational time for each analysis. Increasing the number of options, stages and states are expected to improve the overall results.

4. Use of Discrete Values: This model only considers discrete values for Financial States and for few other parameters, which means that the optimal results obtained might be a reasonably good approximation of optimal solutions.

5. Use of Financial Parameters Only: The mathematical model used here is basically a financial model. Hence, this model can be used only for parameters that can be linked to financial impact to the project. However, due to any reason, if non-financial parameters must be included in the analysis, then the model must be modified to use qualitative

states instead of Financial States. The use of qualitative states would require a very precise description of each state.

6. Although this research work focuses only on a few aspects of PPPs with Availability Payments, this research work can be expanded further for satisfying both public sector and the private sector objectives. The model developed and discussed in this research work focuses only on two objectives. However, additional objectives can be conveniently included in this model and results to more complex situations can be obtained.

## Appendix 1

### Debt and Equity Financing (reproduced here from Sharma et al 2010)

PPP projects are financed on the basis of expected revenues from project operations. If a project is expected to yield large revenues, sufficient debt financing from the financial market can be obtained. When the expected revenues fall short, debt financing may not cover total project costs and thus may create a financial gap. The financial gap needs to be closed with funds from either the public or the private sector. Equity holders take the entire downside risk and get repaid after debt service. This leads to the three issues. First, private partners are willing to invest in PPP projects only when they anticipate a high rate of return or minimum IRR from the investments. If the project is not sufficiently profitable, private partners will not spend a penny or take the risk. Therefore, public agencies may have to give away a significant share from the total profit to attract private investments, even if equity investments may be just a small percentage of the financial gap. Second, public agencies must protect their interests and ensure that private partners do not abandon projects when those partners obtain sufficient profits from PPP projects earlier than expected. An earlier exit from PPP projects may benefit private partners because they could reduce their operation, maintenance, or rehabilitation costs. Private partners are thus required to guarantee a minimum amount of investment to reduce the public agencies' risk. Third, strong public resistance to high private profit in PPP projects pushes many public agencies to limit the rate of return for private investments.

## Appendix 2

## Multi-objective Deterministic Dynamic Programming (MODDP) Model

$$MAP^P = \underset{MAP^P}{\arg min} \sum_{t=1}^{T} \{w_1 \cdot [(MAP_t^P - D_t) + RSL_t]\} + w_2 \cdot |CFS_t - FSA_t|$$

$$\text{where } RSL_t = \begin{cases} 0 & t < T \\ f_{RSL\ Costs} & t = T \end{cases}$$

$f_{\text{Financial State}} \leq \text{ULP}$

$f_{\text{Financial State}} \geq \text{LLP}$

$f_{\text{RSL cost}} \leq \text{MaxEMC}_T$

$f_{\text{RSL cost}} \geq \text{MinEMC}_T$

$$f_t(FSR) = \underset{MAP_P}{min.} \Bigg[ (Expected\ MOF | FSR_t, MAP^P) + \sum_{FSA \in \Omega} p_{FSA@\ t+1} \left\{ \sum_{t'=t+1}^{T} w_1 (MAP_{t'}^P - D_{t'} + RSL_{t'}) \right\} + w_2 |CFS_{t'} - FSA_{t'}| \Bigg]$$

Where,

$D_t$ = Deduction

## Appendix 3

## Multi-objective Stochastic Dynamic Programming Model Using Simulation

## (MO$\tilde{S}$DP)

$$MAP^P = \underset{MAP^P}{\arg min} \sum_{t=1}^{T} \{w_1 \cdot [(MAP_t^P - \widetilde{D_t}) + RSL_t]\} + w_2 \cdot |CFS_t - FSA_t|$$

where $RSL_t = \begin{cases} 0 & t < T \\ f_{RSL\ Costs} & t = T \end{cases}$

$f_{\text{Financial State}} \leq \text{ULP}$

$f_{\text{Financial State}} \geq \text{LLP}$

$f_{\text{RSL cost}} \leq \text{MaxEMC}_\text{T}$

$f_{\text{RSL cost}} \geq \text{MinEMC}_\text{T}$

$$f_t(FSR) = \underset{MAP_P}{min.} \Bigg[ (Expected\ MOF | FSR_t, MAP^P) + \sum_{FSA \in \Omega} p_{FSA@\ t+1} \left\{ \sum_{t'=t+1}^{T} w_1 (MAP_{t'}^P - \widetilde{D_{t'}} + RSL_{t'}) \right\} + w_2 |CFS_{t'} - FSA_{t'}| \Bigg]$$

Where, $\widetilde{D_t}$ = Deduction obtained through simulations

## Appendix 4

## Availability Payment Schedule

| Year | Semi Yearly Payment ($M) |
|---|---|
| 2009 | -50 |
| 2013 | 17.73 |
| 2014 | 17.75 |
| 2014 | 17.78 |
| 2015 | 17.80 |
| 2015 | 17.83 |
| 2016 | 17.85 |
| 2016 | 17.88 |
| 2017 | 17.90 |
| 2017 | 17.93 |
| 2018 | 17.95 |
| 2018 | 17.98 |
| 2019 | 18 |
| 2019 | 18.13 |
| 2020 | 18.12 |
| 2020 | 18.16 |

| Year | Semi Yearly Payment ($M) |
|---|---|
| 2021 | 18.15 |
| 2021 | 18.28 |
| 2022 | 18.22 |
| 2022 | 18.36 |
| 2023 | 18.3 |
| 2023 | 18.44 |
| 2024 | 18.43 |
| 2024 | 18.47 |
| 2025 | 18.46 |
| 2025 | 18.6 |
| 2026 | 18.54 |
| 2026 | 18.68 |
| 2027 | 18.62 |
| 2027 | 18.77 |
| 2028 | 18.76 |
| 2028 | 18.8 |

| Year | Semi Yearly Payment ($M) |
|---|---|
| 2029 | 18.79 |
| 2029 | 18.94 |
| 2030 | 18.88 |
| 2030 | 19.03 |
| 2031 | 18.97 |
| 2031 | 19.13 |
| 2032 | 19.12 |
| 2032 | 19.17 |
| 2033 | 19.16 |
| 2033 | 19.32 |
| 2034 | 19.26 |
| 2034 | 19.42 |
| 2035 | 19.36 |
| 2035 | 19.52 |
| 2036 | 19.52 |
| 2036 | 19.57 |

| Year | Semi Yearly Payment ($M) |
|---|---|
| 2037 | 19.57 |
| 2037 | 19.73 |
| 2038 | 19.67 |
| 2038 | 19.84 |
| 2039 | 19.78 |
| 2039 | 19.95 |
| 2040 | 19.95 |
| 2040 | 20 |
| 2041 | 20.01 |
| 2041 | 20.17 |
| 2042 | 20.12 |
| 2042 | 20.29 |
| 2043 | 20.24 |

## Appendix 5

## Presidio Parkway Project Sample Criteria For Deduction

| TABLE 4.2 - OPERATING PERIOD O&M WORK REQUIREMENTS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Element Category | Required Task | ID | Minimum Performance Requirements | O&M Noncompliance Event Classification | Cure Period | Interval of Recurrence | Long Cure Priority Noncompliance? | O&M Noncompliance Adjustments (for new or recurred events) (High Priority / Mid Priority / Low Priority Hours) |
| **Inspection & Reporting** | | | | | | | | |
| Level of Service Rating Program | Conduct a quarterly rating in accordance with Module 4 of the Department's Level of Service Handbook (LOS2000). | 1 | Meet a minimum quarterly LOS2000 rating calculated in accordance with the Department's evaluation system for individual maintenance elements and overall system. | D | N/A | N/A | | $1,000 |
| | Conduct an annual rating in accordance with Module 4 of the Department's Level of Service Handbook (LOS2000). | 2 | Meet a minimum annual LOS2000 rating calculated in accordance with the Department's evaluation system for individual maintenance elements and overall system. | D | N/A | N/A | | $1,000 |
| O&M Plan | Initial O&M Plan. | 3 | Submit the draft O&M Plan to the Department for review and comment 90 days prior to NTP 2. | A | N/A | 24 Hours | | |
| | | 4 | Submit the final O&M Plan to the Department for review and comment 30 days prior to NTP 2. | A | N/A | 24 Hours | | |
| | Annual Updates to the O&M Plan. | 5 | Within 45 days prior to the beginning of each Fiscal Year after NTP 2, update the O&M Plan and submit it to the Department for review and comment. | A | N/A | 24 Hours | | |
| O&M Monthly and Annual Reports | O&M Monthly Reports. | 6 | Beginning from NTP 2, deliver the O&M Monthly Report to the Department no later than the 7th day of the subsequent month. | A | N/A | 24 Hours | | |
| | O&M Annual Reports. | 7 | Beginning from NTP 2, deliver the O&M Annual Report to the Department no later than the 30th day of the subsequent Fiscal Year. | A | N/A | 24 Hours | | |
| Renewal Work Plan | Initial Renewal Work Plan | 8 | Submit the five-year Renewal Work Plan to the Department for review and comment 45 days prior to NTP 2. | A | N/A | 24 Hours | | |
| | Annual Updates to the Renewal Work Plan | 9 | Within 45 days prior to the beginning of each Fiscal Year after NTP 2, update the Renewal Work Plan and submit it to the Department for review and comment. | A | N/A | 24 Hours | | |
| Renewal Work Report | Renewal Work Reports. | 10 | Beginning from NTP 2, deliver the Renewal Work Report, including any as-built drawings, to the Department no later than the 30th day of the subsequent Fiscal Year. | A | N/A | 24 Hours | | |
| Emergency Reporting | Emergency Reports. | 11 | Provide the Department with a detailed damage report after the occurrence of an Emergency, as detailed in Section 1.9. | A | 24 Hours | 24 Hours | | |

**TABLE 4.2 - OPERATING PERIOD O&M WORK REQUIREMENTS**

| Element Category | Required Task | ID | Minimum Performance Requirements | O&M Noncompliance Event Classification | Cure Period | Interval of Recurrence | Long Cure Priority Noncompliance? | O&M Noncompliance Adjustments (for new or recurred events) (High Priority / Mid Priority / Low Priority Hours) |
|---|---|---|---|---|---|---|---|---|
| Integrated Maintenance Management System (IMMS) | Provide inventory data to the Department for incorporation into the IMMS. | 12 | Provide updated hard copy inventory data to the Department with each O&M Monthly Report (as changes occur) for all applicable facility elements. | A | 30 Days | 3 Days | | |
| | | 13 | Beginning from Substantial Completion, conduct a complete inventory review of all facility elements every fifth Fiscal Year and provide inventory data to the Department no later than the 30th day of each Fiscal Year in which an inventory review is conducted. | A | N/A | 3 Days | | |
| Maintenance Patrols | Conduct maintenance patrols to detect any issues on the facility that need to be addressed. | 14 | Conduct a daily maintenance patrol and visual inspection of the entire facility to identify any incidents or deficiencies. | B | N/A | 24 Hours | | |
| Sustainability Management Plan | Preparation of a revised Sustainability Management Plan for the O&M period. | 15 | Submit a sustainability program per guidance in Division I, Section 1.5.5 and Division II, Section 4 Chapter 1.14. | A | N/A | 24 Hours | | |
| **Flexible Pavement** | | | | | | | | |
| Flexible Pavement | Maintain flexible pavement at acceptable condition and level of safety for traveling public. | 16 | Ride quality to be maintained at International Roughness Index (IRI) of less than or equal to 95. | C | 90 Days | 5 Days | Yes | |
| | | 17 | Repair all cracks greater than or equal to 0.25 inches in width. | B | 90 Days | 5 Days | Yes | |
| | | 18 | Repair all settlement/depression greater than 1.5 inches in depth over any 50 ft. length. | C | 30 Days | 5 Days | Yes | |
| | | 19 | Repair all wheel ruts greater than 1 inch deep. | C | 90 Days | 5 Days | Yes | |
| | | 20 | Repair drip-track ruts over 0.5 inches deep. | C | 90 Days | 5 Days | Yes | |
| | | 21 | Repair alligator cracking in excess of 30%. | B | 90 Days | 5 Days | Yes | |
| | | 22 | Repair all pot holes and slippage areas greater than 0.5 square feet in area and/or 1.5 inches deep. | C | 24 Hours | 24 Hours | | |
| | | 23 | Inspect pavement surface in accordance with Maintenance Manual Volume II, Section 4 for the A Family. | B | N/A | 5 Days | | |

(Note: The figure above was taken from an online document. Since the original figure did not have high resolution the image might get blurred when taking print out. Please refer the following link to directly down load the document: http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/Procurement%20Documents/technical%20specifications/Presidio%20Parkway_Vol%20II_09JUL2010_FINAL%20RFP.pdf)

# Appendix 6

## Unavailability Factors for Presidio Parkway Project

| Segment | Lanes Closed | North- or Southbound (Weekdays) High Priority Hours (07.00-11.00 (SB), 16.00-19.00(NB)) | North- or Southbound (Weekdays) Mid Priority Hours (11.00-16.00, 19.00-21.00, 06.00-07.00, 07.00-11.00(NB), 16.00-19.00(SB)) | North- or Southbound (Weekdays) Low Priority Hours (21.00-06.00) | North- or Southbound (Weekends) High Priority Hours (12.00-19.00) | North- or Southbound (Weekends) Mid Priority Hours (09.00-12.00, 19.00-21.00) | North- or Southbound (Weekends) Low Priority Hours (21.00-09.00) |
|---|---|---|---|---|---|---|---|
| Segments 5 lanes in each direction | 1 | 0.10 | 0.07 | 0.02 | 0.09 | 0.07 | 0.0] |
| | 2 | 0.39 | 0.26 | 0.06 | 0.37 | 0.27 | 0.08 |
| | 3 | 0.69 | 0.46 | 0.10 | 0.64 | 0.48 | 0.14 |
| | 4 | 2.16 | 1.45 | 0.32 | 2.01 | 1.51 | 0.43 |
| | 5 | 12.00 | 12.00 | 6.20 | 12.00 | 12.00 | 8.23 |
| | | | | | | | |
| Segments 4 lanes in each direction | 1 | 0.10 | 0.07 | 0.02 | 0.10 | 0.10 | 0.02 |
| | 2 | 0.69 | 0.46 | 0.10 | 0.60 | 0.50 | 0.14 |
| | 3 | 2.16 | 1.45 | 0.32 | 2.00 | 1.50 | 0.43 |
| | 4 | 12.00 | 12.00 | 5.27 | 12.00 | 12.00 | 6.99 |
| | | | | | | | |
| Segments with up to 3 lanes in each direction | 1 | 0.18 | 0.12 | 0.03 | 0.20 | 0.10 | 0.04 |
| | 2 | 0.64 | 0.43 | 0.10 | 0.60 | 0.40 | 0.13 |
| | 3 | 12.00 | 12.00 | 5.03 | 12.00 | 12.00 | 6.67 |

(Note: The figure above was taken from an online document. Since the original figure did not have high resolution the image might get blurred when taking print out. Please refer the following link to directly down load the document: http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/Procurement%20Documents/public%20private%20partnership%20agreement/P3%20Agreement%20Appendices%202%20through%2023%20FINAL%20070910.pdf)

**Appendix 7**

**Equity Cash Flow For Presidio Parkway Project With 30 Year Concession Period**

| **Concessionaire's Perspective** | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|---|---|---|---|
| **Expenses** | | | | | | | | | |
| Equity | 50.00 | | | | | | | | |
| Taxes | | | | | 2.32 | 4.64 | 4.64 | 4.64 | 4.64 |
| Operation Costs | | | | | 0.42 | 0.83 | 0.83 | 0.83 | 0.83 |
| Maintenance and Rehab Costs | | | | | 1.03 | 2.06 | 0.00 | 2.06 | 0.00 |
| Debt Repayment | | | | | | | | | |
| Senior Debt Repayment | | | | | 13.04 | 13.04 | 13.04 | | |
| TIFIA Repayment | | | | | | | | 22.64 | 22.64 |
| **Earnings** | | | | | | | | | |
| Profit from Construction (3% of construction cost ) | | | | | 15.03 | | | | |
| Availability Payment (Design and Financing Part) | | | | | 15.00 | 30.00 | 30.00 | 30.00 | 30.00 |
| Availability Payment (O&M Part) | | | | | 2.73 | 5.53 | 5.63 | 5.73 | 5.83 |
| **Annual Equity Cash Flows For Concessionaire** | -50.0 | | | | 15.95 | 14.95 | 17.11 | 5.55 | 7.71 |

| **Concessionaire's Perspective** | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Expenses** | | | | | | | | | | |
| Equity | | | | | | | | | | |
| Taxes | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 |
| Operation Costs | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 |
| Maintenance and Rehab Costs | 2.06 | 0.03 | 2.06 | 0.69 | 2.06 | 0.69 | 2.06 | 0.69 | 2.06 | 0.69 |
| Debt Repayment | | | | | | | | | | |
| Senior Debt Repayment | | | | | | | | | | |
| TIFIA Repayment | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 |
| **Earnings** | | | | | | | | | | |
| Profit from Construction | | | | | | | | | | |
| Availability Payment (Design & Financing) | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 |
| Availability Payment (O&M) | 5.93 | 6.13 | 6.28 | 6.43 | 6.58 | 6.74 | 6.90 | 7.06 | 7.22 | 7.39 |
| **Annual Equity Cash Flows For Concessionaire** | 5.75 | 7.98 | 6.10 | 7.62 | 6.40 | 7.93 | 6.72 | 8.25 | 7.04 | 8.58 |

| Concessionaire's Perspective | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 | 2034 | 2035 | 2036 | 2037 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Expenses** | | | | | | | | | | |
| Equity | | | | | | | | | | |
| Taxes | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 |
| Operation Costs | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 |
| Maintenance and Rehab Costs | 2.06 | 0.69 | 2.06 | 0.69 | 2.06 | 0.69 | 2.06 | 0.69 | 2.06 | 0.69 |
| Debt Repayment | | | | | | | | | | |
| Senior Debt Repayment | | | | | | | | | | |
| TIFIA Repayment | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 |
| **Earnings** | | | | | | | | | | |
| Profit from Construction | | | | | | | | | | |
| Availability Payment (Design & Financing) | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 |
| Availability Payment (O&M) | 7.56 | 7.73 | 7.91 | 8.10 | 8.29 | 8.48 | 8.68 | 8.88 | 9.09 | 9.30 |
| **Annual Equity Cash Flows For Concessionaire** | 7.38 | 8.92 | 7.73 | 9.29 | 8.11 | 9.67 | 8.50 | 10.07 | 8.91 | 10.49 |

| **Concessionaire's Perspective** | 2038 | 2039 | 2040 | 2041 | 2042 | 2043 |
|---|---|---|---|---|---|---|
| **Expenses** | | | | | | |
| Equity | | | | | | |
| Taxes | 4.64 | 4.64 | 4.64 | 4.64 | 4.64 | 2.32 |
| Operation Costs | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.42 |
| Maintenance and Rehab Costs | 2.06 | 0.69 | 2.06 | 0.69 | 2.06 | 1.03 |
| Debt Repayment | | | | | | |
| Senior Debt Repayment | | | | | | |
| TIFIA Repayment | 22.64 | 22.64 | 22.64 | 22.64 | 22.64 | |
| **Earnings** | | | | | | |
| Profit from Construction | | | | | | |
| Availability Payment (Design & Financing) | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 15.00 |
| Availability Payment (O&M) | 9.51 | 9.73 | 9.95 | 10.18 | 10.41 | 5.24 |
| **Annual Equity Cash Flows For Concessionaire** | 9.33 | 10.92 | 9.77 | 11.37 | 10.23 | 16.47 |

# Appendix 8

## Backward-Pass Solution

### Stage 6 Computations

During stage 6 of the project, the financial condition can be between $139M to $182M (Table 4). Hence, we observe that the final stage can take 44 states (182-139 + 1= 44). Thus, with 5 values of decision variables, we will have 44*5 = 220 rows in the Excel sheet during the $6^{th}$ stage.

During the final stage, the project will be in a state between $139M and $182M. The private sector will be eligible for availability payment and will also have the deductions. Apart from this, the Remaining Life Cycle costs will also be incurred after the stage 6. This leads to the following calculations:

$$f_6(182) = w1 * [\ 33.93*5 - E[D] + RSL]$$

$$+ w2 * [\{146 - (182 + 33.93*5 + FA - E[D])\}^2]^{½}$$

In the above formulation, "182+33.73*5+FA" gives us the new financial state without deductions. When deductions are applied to this form, we obtain a new financial state with deductions. Similarly, when the MAP of 34.73 is analyzed, we get "182+34.73*5+FA." In these formulations, we can observe the MAP as the part of the equation. However, the term FA, which stands for Financial Adjustment, will have to be calculated by subtracting MAPs for 5-years from equity cash flows without deductions. In doing so, it was felt that the calculations will become confusing. Hence, these calculations were done using the available data.

It was observed that under the conditions of no deduction, the private sector's financial state during final stage will be $182.04M. Similarly, the private sector's financial state during the second last stage will be $134.7M (Table 4). This jump in financial state occurs since the private sector receives money as per the equity cash flows without any deductions. The financial jump observed here corresponds to MAP of $35.53M. On the other hand, if the MAP of $33.93M is used in the equity cash flows, everything other than the MAPs will remain the same. Hence, in such condition, the private sector's Financial State will be less by the difference between the MAPs. This can be shown below:

| | |
|---|---|
| MAP $35.53M | 5*(35.53–35.53) = 0 |
| MAP $35.08M | 5*(35.53-35.13) = 2.00 |
| MAP $34.63M, | 5*(35.53-34.73) = 4.00 |
| MAP $34.18M | 5*(35.53-34.33) = 6.00 |
| MAP $33.73M | 5*(35.53-33.93) = 8.00 |

Furthermore, the private sector will reach a financial state of $240.8M (Table 4) if there is no deduction. This requires a Financial Jump of 240.8 – 182.04 = $58.76 M across the last stage. Thus, if we want to jump stages as well as consider different MAPs together, we must consider financial jumps for stages as well as financial jumps for different MAPs. Thus, we can calculate financial jumps for different MAPs as shown below:

MAP \$35.53M CFS = 182.04 – 5*(35.53-35.53) + 58.76 = 182.04 + 58.76

MAP \$35.13M CFS = 182.04 – 5*(35.53-35.13) + 58.76 = 182.04 + 60.76

MAP \$34.73M, CFS = 182.04 – 5*(35.53-34.73) + 58.76 = 182.04 + 62.76

MAP \$34.33M CFS = 182.04 – 5*(35.53-34.33) + 58.76= 182.04 + 64.76

MAP \$33.93M CFS = 182.04 – 5*(35.53-33.93) + 58.76 = 182.04 + 66.76

Where, CFS is the Control Financial State

Thus, instead of using previously defined formulation, the above formulation will be used and can be expressed as shown below:

$$\text{Minimize} \quad w_1 \cdot (MAP - D_i + RSL_t) + $$

$$w_2 \cdot |\text{Control Financial State}_i - (\text{Financial State Realized}_{i-1} + FJ - D_i|$$

where FJ is the financial jump across states and stages and can be expressed as

$$FJ = MAP + FA$$

Furthermore, assuming that the weights w1 equals 0.9 and w2 equals 0.1 as well as using the previously calculated values of expected deductions (as calculated in Section 4.2.1.2) and RSL costs (as discussed in Section 4.2.2.2) to be \$4.16 (calculated as \$0.832M*5) and \$591M, we obtain the values of $f_6$ as shown below:

(Note that following calculations use MAPs for 5-years. So, 169.65 represents 5 times the MAP of 33.93, 171.65 represents 5*34.33, 173.65 represents 5*34.73, 175.65 represents 5*35.13 and 177.65 represents 5*35.53. Also note that the absolute value was obtained by taking square and then taking square root of the same term)

$f_6(139) = 0.9*[169.65–4.16+591]+0.1*[\{197-(139+50.76-4.16)\}^2]^{½}= 681.97$ X

$f_6(139) = 0.9*[171.65–4.16+591]+0.1*[\{197-(139+52.76-4.16)\}^2]^{½}= 683.57$ X

$f_6(139) = 0.9*[173.65–4.16+591]+0.1*[\{197-(139+54.76-4.16)\}^2]^{½}= 685.18$ *

$f_6(139) = 0.9*[175.65–4.16+591]+0.1*[\{197-(139+56.76-4.16)\}^2]^{½}= 686.77$

$f_6(139) = 0.9*[177.65–4.16+591]+0.1*[\{197-(139+58.76-4.16)\}^2]^{½}= 688.37$

$f_6(140) = 0.9*[169.65–4.16+591]+0.1*[\{197-(140+50.76-4.16)\}^2]^{½}= 681.87$ X

$f_6(140) = 0.9*[171.65–4.16+591]+0.1*[\{197-(140+52.76-4.16)\}^2]^{½}= 683.47$ *

$f_6(140) = 0.9*[173.65–4.16+591]+0.1*[\{197-(140+54.76-4.16)\}^2]^{½}= 685.07$

$f_6(140) = 0.9*[175.65–4.16+591]+0.1*[\{197-(140+56.76-4.16)\}^2]^{½}= 686.67$

$f_6(140) =0.9*[177.65–4.16+591]+0.1*[\{197-(140+58.76-4.16)\}^2]^{½}= 688.27$

……

……

$f_6(182) = 0.9*[169.65–4.16+591]+0.1*[\{197-(182+50.76-4.16)\}^2]^{½}= 683.99$ *

$f_6(182) = 0.9*[171.65–4.16+591]+0.1*[\{197-(182+52.76-4.16)\}^2]^{½}= 685.99$

$f_6(182) = 0.9*[173.65–4.16+591]+0.1*[\{197-(182+54.76-4.16)\}^2]^{½}= 687.99$

$f_6(182) = 0.9*[175.65–4.16+591]+0.1*[\{197-(182+56.76-4.16)\}^2]^{½}= 689.99$

$f_6(182) =0.9*[177.65–4.16+591]+0.1*[\{197-(182+58.76-4.16)\}^2]^{½}= 691.99$

In the above calculations, starred values represent the optimal values. It can be seen that if the states of $139M and $140M are realized before stage 6, the best strategy is to select the best alternative of the MAP of $33.93M (since first row has minimum value of 681.97). However, it is observed that when the private sector is at those low financial levels and deductions are applied, the private sector will end up in a state that will not satisfy their IRR. Hence, this option must not be selected. Similar is the case with the immediately next alternative of the MAP of $34.33M. Hence, we select the third alternative of the MAP of $34.73M. On the other hand, when the state of $182M is achieved, the best strategy is again to have a MAP of $33.93M. The above results for the state of $182M are intuitive since the above calculations are suggesting that when the private sector is at the ideal state, the smallest MAP should be selected (i.e., $33.93M in this case study).

Once these values are obtained, the calculations can focus on the previous (in this case, it is stage 5).

### Stage 5 Computations

The stage 5 computations are very much similar to the stage 6 computations; however, there are a few changes. The recursion formula will be used to link the stage 5 and stage 6 appropriately and obtain an optimal solution. Also, we will see that the RSL costs will no longer be included in the calculations.

During stage 5 of the project, the financial condition can be between $100 and $135M (as seen from Table 4). Hence, we observe that the final stage can take 36 states (135-100+1). Thus, with 5 values of decision variables, we will have 36*5 = 180 rows in the Excel sheet during the 5<sup>th</sup> stage.

During this stage, the project will be in a state between $100M and $135M. The private sector will be eligible for availability payment and will also have the deductions. This leads to the following calculations:

$$f_5(100) = \quad w1 * [\ 33.93*5 - \text{Exp}[D(\xi)]] + w2 * |146 - (100 + FJ - \text{Exp}[D(\xi)])|$$

Using the values of w1, w2 and expected deductions as in stage 6 we get:

$$f_5(100) = 0.9*[169.65 - 4.16] + 0.1*[\{146-(100+39.3-4.16)\}^2]^{1/2} = 150.02\ *$$

$f_5(100) = 0.9*[171.65–4.16]+0.1*[\{146-(100+41.3-4.16)\}^2]^{½} = 151.62$

$f_5(100) = 0.9*[173.65–4.16]+0.1*[\{146-(100+43.3-4.16)\}^2]^{½} = 153.22$

$f_5(100) = 0.9*[175.65–4.16]+0.1*[\{146-(100+45.3-4.16)\}^2]^{½} = 154.82$

$f_5(100) = 0.9*[177.65–4.16]+0.1*[\{146-(100+57.3-4.16)\}^2]^{½} = 156.42$

$f_5(101) = 0.9*[169.65–4.16]+0.1*[\{146-(101+39.3-4.16)\}^2]^{½} = 149.92$ *

$f_5(101) = 0.9*[171.65–4.16]+0.1*[\{146-(101+41.3-4.16)\}^2]^{½} = 151.52$

$f_5(101) = 0.9*[173.65–4.16]+0.1*[\{146-(101+43.3-4.16)\}^2]^{½} = 153.12$

$f_5(101) = 0.9*[175.65–4.16]+0.1*[\{146-(101+45.3-4.16)\}^2]^{½} = 154.72$

$f_5(101) = 0.9*[177.65–4.16]+0.1*[\{146-(101+57.3-4.16)\}^2]^{½} = 156.32$

…

…

$f_5(135) = 0.9*[169.65–4.16]+0.1*[\{146-(135+39.3-4.16)\}^2]^{½} = 151.35$ *

$f_5(135) = 0.9*[171.65–4.16]+0.1*[\{146-(135+41.3-4.16)\}^2]^{½} = 153.35$

$f_5(135) = 0.9*[173.65–4.16]+0.1*[\{146-(135+43.3-4.16)\}^2]^{½} = 155.35$

$f_5(135) = 0.9*[175.65–4.16]+0.1*[\{146-(135+45.3-4.16)\}^2]^{½}= 157.35$

$f_5(135) = 0.9*[177.65–4.16]+0.1*[\{146-(135+57.3-4.16)\}^2]^{½}= 159.35$

In the above calculations starred values represent the optimal values only for the 5th stage but these are not the optimal values for all the remaining stages. Also note that the expected value for deduction used in this stage is same as in stage 6, since it is assumed here that the distribution of deductions may not change. Furthermore, the remaining life cycle costs are not used in above calculations.

The above computations provide the values of objective function for stage 5 only. These do not have values of stage $f_6$. Hence, we must use the recursion function to obtain the optimal values. The use of the recursion function will ensure that the strategy used during stage 5 will be best for stages 5 and 6.

In order to use the recursion function, we must estimate the new state that will be realized after stage 5. Hence, let us assume that the state realized before stage 5 was \$130M. We further assume that the deduction realized was \$0.832M. This leads us to the new state for all the MAP values as below:

$f'_{5\text{ to }6}(\text{New}) = f_5(\text{Current}) + FJ - Exp[D(\xi)]$

$f_5(87) = 130+ 39.3 – 0.94 *5 = 165.13 \sim 165$

$f_5(87)$ = 130+ 41.3 – 0.94 *5 = 167.13 ~ 167

$f_5(87)$ = 130+ 43.3 – 0.94 *5 = 169.13 ~ 169

$f_5(87)$ = 130+ 45.3 – 0.94 *5= 171.13 ~ 171

$f_5(87)$ = 130+ 47.3 – 0.94 *5= 173.13 ~ 173

The recursion formula must be used now for the states established above. The recursion formula can be expressed as:

$f^{\hat{}}_{\text{Recursion (t, t+1)}}$ = Minimize (Realized Combined Objective Function) $_t$

+ (Expected Combined Objective Function) $_{t+1}$

For all these states, we refer the stage 6 computations.

For $f_6$ (165) we observe that

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 165.0 | 33.93 | 682.2995954* | MAP = 33.93<br>Objective Function = 682.29 |
| 165.0 | 34.33 | 684.2995954 | |
| 165.0 | 34.73 | 686.2995954 | |
| 165.0 | 35.13 | 688.2995954 | |
| 165.0 | 35.53 | 690.2995954 | |

For $f_6$ (167) we observe that

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 167.0 | 33.93 | 682.4995954* | |
| 167.0 | 34.33 | 684.4995954 | MAP = 33.93 |
| 167.0 | 34.73 | 686.4995954 | |
| 167.0 | 35.13 | 688.4995954 | Objective Function = 682.49 |
| 167.0 | 35.53 | 690.4995954 | |

For $f_6$ (169) we observe that

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 169.0 | 33.93 | 682.6995954* | |
| 169.0 | 34.33 | 684.6995954 | MAP = 33.73 |
| 169.0 | 34.73 | 686.6995954 | |
| 169.0 | 35.13 | 688.6995954 | Objective Function = 682.69 |
| 169.0 | 35.53 | 690.6995954 | |

For $f_6$ (171) we observe that

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 171.0 | 33.93 | 682.8996* | |
| 171.0 | 34.33 | 684.8996 | MAP = 33.73 |
| 171.0 | 34.73 | 686.8996 | |
| 171.0 | 35.13 | 688.8996 | Objective Function = 682.89 |

| | | | |
|---|---|---|---|
| 171.0 | 35.53 | 690.8996 | |

For $f_6$ (173) we observe that

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 173.0 | 33.93 | 683.0996* | MAP = 33.73<br><br>Objective Function = 683.09 |
| 173.0 | 34.33 | 685.0996 | |
| 173.0 | 34.73 | 687.0996 | |
| 173.0 | 35.13 | 689.0996 | |
| 173.0 | 35.53 | 691.0996 | |

Adding these optimal values of $f_6$ with optimal values of $f_5$ we get the following calculations:

$f_5(130) = 0.9*[169.65–4.16]+0.1*[\{146-(130+39.3-4.16)\}^2]^{½}= 150.85$

$f_5(130) = 0.9*[171.65–4.16]+0.1*[\{146-(130+41.3-4.16)\}^2]^{½}= 152.85$

$f_5(130) = 0.9*[173.65–4.16]+0.1*[\{146-(130+43.3-4.16)\}^2]^{½}= 154.85$

$f_5(130) = 0.9*[175.65–4.16]+0.1*[\{146-(130+45.3-4.16)\}^2]^{½}= 156.85$

$f_5(130) = 0.9*[177.65–4.16]+0.1*[\{146-(130+57.3-4.16)\}^2]^{½}= 158.85$

$f_5(130.0)$ = 150.85+ 682.29 = 833.15* → Relates to State of $f_6(165)$

→



→

→

$f_5(130.0) = 152.85 + 682.49 = 835.35$ Relates to State of $f_6(167)$

$f_5(130.0) = 154.85 + 682.69 = 837.55$ Relates to State of $f_6(169)$

$f_5(130.0) = 156.85 + 682.89 = 839.75$ Relates to State of $f_6(171)$

$f_5(130.0) = 158.85 + 683.09 = 841.95$ Relates to State of $f_6(173)$

In the above calculations, the value of 833.15 is the optimal value for stages 5 and 6 considered together. Hence, if a state of 130 is realized before stage 5, the MAP (decision variable) of 33.93 must be chosen.

These calculations must be carried out for all the remaining states until the calculations reach the beginning stage. The computation procedure used for stage 5 must also be used for stages 4, 3, 2, and 1. Once the calculations for all the stages are obtained, the forward calculations can begin. Following paragraphs shows the computations for stage 1.

### Stage 1 Computations

During Stage 1 the private sector's financial condition can take any value between -\$35.72M and -\$34.05M (i.e., between -\$36M and -\$34M as seen from Table 4).Hence, we observe that the final stage can take 3 states (-34-(-36)+1). Thus, with 5 values of decision variables, we will have 3*5 = 15 rows in the Excel sheet during the 1$^{st}$ stage. During this stage, the project will be in a state between \$100M and \$135M. The private sector will be eligible for availability payment and will also have the deductions. This leads to the following calculations:

$f_1(-34) =$ w1 * [ 33.93*5 – Exp[D(ξ)] ]

+ w2 * |[{-36.0 - (-34.0 + FJ - Exp[D(ξ)])|

Assuming that w1=0.9 and w2 = 0.1 we perform the following calculations:

$f_1(-36) = 0.9*[169.65–4.16]+0.1*[\{-36-(-36+43.08-4.16)\}^2]^{½}= 149.54*$

$f_1(-36) = 0.9*[171.65–4.16]+0.1*[\{-36-(-36+45.08-4.16)\}^2]^{½}= 151.14$

$f_1(-36) = 0.9*[173.65–4.16]+0.1*[\{-36-(-36+47.08-4.16)\}^2]^{½}= 152.74$

$f_1(-36) = 0.9*[175.65–4.16]+0.1*[\{-36-(-36+49.08-4.16)\}^2]^{½}= 154.34$

$f_1(-36) = 0.9*[177.65–4.16]+0.1*[\{-36-(-36+51.08-4.16)\}^2]^{½}= 156.33$

$f_1(-35) = 0.9*[169.65–4.16]+0.1*[\{-36-(-35+43.08-4.16)\}^2]^{½}= 149.44$ *

$f_1(-35) = 0.9*[171.65–4.16]+0.1*[\{-36-(-35+45.08-4.16)\}^2]^{½}= 151.04$

$f_1(-35) = 0.9*[173.65–4.16]+0.1*[\{-36-(-35+47.08-4.16)\}^2]^{½}= 152.64$

$f_1(-35) = 0.9*[175.65–4.16]+0.1*[\{-36-(-35+49.08-4.16)\}^2]^{½}= 154.43$

$f_1(-35) = 0.9*[177.65–4.16]+0.1*[\{-36-(-35+51.08-4.16)\}^2]^{½}= 156.43$

$f_1(-34) = 0.9*[169.65–4.16]+0.1*[\{-36-(-34+43.08-4.16)\}^2]^{½}= 149.34$ *

$f_1(-34) = 0.9*[171.65–4.16]+0.1*[\{-36-(-34+45.08-4.16)\}^2]^{½}= 150.94$

$f_1(-34) = 0.9*[173.65–4.16]+0.1*[\{-36-(-34+47.08-4.16)\}^2]^{½}= 152.54$

$f_1(-34) = 0.9*[175.65–4.16]+0.1*[\{-36-(-34+49.08-4.16)\}^2]^{½}= 154.53$

$f_1(-34) = 0.9*[177.65–4.16]+0.1*[\{-36-(-34+51.08-4.16)\}^2]^{½}= 156.53$

In the above calculations starred values represent the optimal values for 1$^{st}$ stage only. Also note that the expected value for deduction used in this stage is same as in stage all the previous stages, since it is assumed here that the distribution of deductions may not change.

The above computations provide the values of objective function for stage 1 only. These do not have values of stage $f_2$ and beyond. Hence, we must use the recursion function to obtain the optimal values. The use of the recursion function will ensure that the strategy used during stage 1 will be best for stages 1 and all the succeeding stages.

In order to use the recursion function, we must estimate the new state that will be realized after stage 1. Hence, let us assume that the state realized before stage 5 was $-34M. We further assume that the deduction realized was $0.832M. This leads us to the new state for all the MAPs as below

$f_1(-34) = -34+ 43.08 – 0.94 *5 = 4.91 \sim 5$

$f_1(-34) = -34 + 45.08 - 0.94 * 5 = 6.91 \sim 7$

$f_1(-34) = -34 + 47.08 - 0.94 * 5 = 8.91 \sim 9$

$f_1(-34) = -34 + 49.08 - 0.94 * 5 = 10.91 \sim 11$

$f_1(-34) = -34 + 51.08 - 0.94 * 5 = 12.91 \sim 13$

The recursion formula must be used now for the states established above. The recursion formula can be expressed as:

$$\hat{f}_{\text{Recursion } (t,\, t+1)} = \text{Minimize (Realized Combined Objective Function)}_t$$
$$+ \text{(Expected Combined Objective Function)}_{t+1}$$

Hence, we look up for these states in the calculations for Stage 2. For Stage 2, we observe the following:

For $f_2$ (5) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 5 | 33.93 | Does Not Exist Since the State of 5 represents a condition that the private sector will quit | MAP = Nil<br>Objective Function = Nil |
| 5 | 34.33 | | |
| 5 | 34.73 | | |
| 5 | 35.13 | | |
| 5 | 35.53 | | |

For $f_2$ (7) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 7 | 33.93 | Infeasible | MAP = 34.73<br><br>Objective Function = 1294.17 |
| 7 | 34.33 | Infeasible | |
| 7 | 34.73 | 1294.401382 | |
| 7 | 35.13 | 1294.201382 | |
| 7 | 35.53 | 1294.175101* | |

For $f_2$ (9) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 9 | 33.93 | Infeasible | MAP = 35.13<br><br>Objective Function = 1292.37 |
| 9 | 34.33 | 1292.601382 | |
| 9 | 34.73 | 1292.401382 | |
| 9 | 35.13 | 1292.375101* | |
| 9 | 35.53 | 1292.575101 | |

For $f_2$ (11) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 11 | 33.93 | 1290.801382 | MAP = 34.73 |
| 11 | 34.33 | 1290.601382 | |
| 11 | 34.73 | 1290.575101* | |

| | | | |
|---|---|---|---|
| 11 | 35.13 | 1290.775101 | Objective Function = 1290.57 |
| 11 | 35.53 | 1290.975101 | |

For $f_2$ (13) we observe that

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 13 | 33.93 | 1288.801382 | MAP = 34.33<br><br>Objective Function = 1288.77 |
| 13 | 34.33 | 1288.775101* | |
| 13 | 34.73 | 1288.975101 | |
| 13 | 35.13 | 1289.175101 | |
| 13 | 35.53 | 1289.53682 | |

We combine the optimal values of Stage 1 with the optimal values for all the stages beyond Stage 1 (in this case it is stage 2 to stage 6) we get the following

$f_1(-34)$ = 149.34 + Infeasible = Infeasible → Relates to State of $f_2(5)$

$f_1(-34)$ = 150.94 + 1294.17 = 1445.12 → Relates to State of $f_2(7)$

$f_1(-34)$ = 152.54 + 1292.37 = 1444.92* → Relates to State of $f_2(9)$

$f_1(-34)$ = 154.53 + 1290.57 = 1445.10 → Relates to State of $f_2(11)$

$f_1(-34)$ = 156.53 + 1288.77 = 1445.30 → Relates to State of $f_2(13)$

In the above calculations, the value of 1444.92 is the minimum value for the combined objective function considering all the stages from Stage 1 to Stage 6. Hence if a state of (–34) is realized after the construction phase MAP of 34.73 must be chosen as the optimal answer.

This concludes the backward-pass Calculations for the model. Once the backward calculations are done the model will be left with tables containing all the calculations. When realization pass calculation begins the model will select the path yielding the minimum combined objective function. The model is developed in such a way that it documents the backward and realization pass calculations for the path selected. Note that for the backward calculations we used expected values, but for the forward calculations, we will use randomly generated deductions. These randomly generated values will follow a discrete random distribution and will be considered as deductions realized during a particular stage.

## Appendix 9

## Deterministic Model With No Recourse

$$MAP^P = \underset{MAP^P}{\arg min} \sum_{t=1}^{T} \{w_1 \cdot [(MAP_t^P - D_t) + RSL_t]\} + w_2 \cdot |CFS_t - FSA_t|$$

$$\text{where } RSL_t = \begin{cases} 0 & t < T \\ f_{RSL\ Costs} & t = T \end{cases}$$

$f_{\text{Financial State}} \leq$ ULP

$f_{\text{Financial State}} \geq$ LLP

$f_{\text{RSL cost}} \leq$ $\text{MaxEMC}_T$

$f_{\text{RSL cost}} \geq$ $\text{MinEMC}_T$

$$f_T(FSR) = \underset{MAP_P}{min.} \Bigg[ (Expected\ MOF | FSR_T, MAP^P) + \sum_{FSA \in \Omega} p_{FSA@\ T+R}\ (Post\_Concession\_M\&R\_Costs_{T+R}) \Bigg]$$

Where,

$D_t$ = Expected Deduction For the Concession Period t

$T$ = Concession Period

R = Remaining design life of the highway (ie post concession life of the highway)

## Appendix 10

## Value of Stochastic Solutions

### USING DIFFERENT CONTROL BOUNDS

| Control Bounds | No Recourse | MO$\tilde{S}$DP Values | VSS With No Recourse |
|---|---|---|---|
| Upper BND | 1449.344 | 1459.54 | 10.196 |
| U and 25% | 1448.744 | 1456.5 | 7.756 |
| 25% to 50% | 1447.444 | 1453.09 | 5.646 |
| 50% to 75% | 1446.244 | 1449.4 | 3.156 |
| 75% and L (Base Case) | 1444.944 | 1446.3 | 1.356 |
| CB as LB | 1444.144 | 1445.51 | 1.366 |

### PRIVATE SECTOR'S RISK APTITUDE

| | No Recourse | MO$\tilde{S}$DP Values | VSS With No Recourse |
|---|---|---|---|
| 8% Return | 1381.044 | 1381.16 | 0.116 |
| 9% Return | 1397.984 | 1399.63 | 1.646 |
| 10% Return | 1416.684 | 1417.96 | 1.276 |
| 8% Return | 1436.124 | 1436.68 | 0.556 |
| 9% Return | 1451.314 | 1456.8 | 5.486 |
| 10% Return | 1478.824 | 1478.85 | 0.026 |

**PRIVATE SECTOR LOSS DURING CONSTRUCTION**

| | No Recourse | MO$\tilde{S}$DP Values | VSS |
|---|---|---|---|
| Loss of 0% (BaseCase) | 1444.944 | 1446.3 | 1.356 |
| Loss of 0.5% | 1448.584 | 1450.23 | 1.646 |
| Loss of 1.0% | 1451.284 | 1452.95 | 1.666 |
| Loss of 1.5% | 1453.044 | 1455.18 | 2.136 |
| Loss of 2.0% | 1455.744 | 1458.71 | 2.966 |
| Loss of 2.5% | 1457.624 | 1461.1 | 3.476 |
| Loss of 3.0% | 1460.324 | 1464.68 | 4.356 |

**PRIVATE SECTORS LEARNING**

| | No Recourse | MO$\tilde{S}$DP Values | VSS With No Recourse |
|---|---|---|---|
| 80% (i..e. 20% Learning ) | 1444.944 | 1446.85 | 1.906 |
| 85% (i.e., 15% Learning) | 1444.944 | 1446.64 | 1.696 |
| 90% (i.e., 10% Learning) | 1444.944 | 1446.54 | 1.596 |
| 95% (i.e., 05% Learning) | 1444.944 | 1446.44 | 1.496 |
| 100%( Base Case) | 1444.944 | 1446.3 | 1.356 |

## Appendix 11

### Sample Calculations For the Realization Pass (Continued from Appendix 9)

The first stage for forward calculations begins with Stage 1. Stage 1 can take any value between -$35.72M and -$34.05M (i.e., between -$36M and -$34M). Hence, we assume and select -$34M as the initial financial state of the private sector. Now, we should locate the value of -$34M in the Stage 1 table, which is readily available to us from the backward-pass. After locating the values for the state -$34M, we can easily obtain an optimal solution for Stage 1 and all the stages after that as shown below.

During Stage 1, the private sector performs and becomes eligible for MAP. However, deductions are applied to MAP for unavailability of asset. These deductions are randomly generated using Monte Carlo simulation. Uniform distribution is used in the calculations (as described in Section 4.2.1.2) having a lower bound value of $0 and upper bound value of $1.66M. The value of $1.664M is obtained by assuming that the private sector will leave the PPP contract midway if the deduction increases beyond $1.664M (since the private sector will have an IRR of less than 11.5%). Hence, we generate random values using RAND() function in MS Excel and using formula RAND()*(b-a) + a (where a is the lower bound value and b is the upper bound value for the distribution).

Let us assume that MS Excel generates a value of $1.3M as deduction for Stage 1. Thus, we replace the expected value of deduction by the realized value of deduction. This will require us to update our model with the realized value and then reevaluate the strategy for remaining stages.

**During Stage 1**

Realizing that the deduction is \$1.3M, the following calculations are carried out to calculate the objective function for the state of. $f_1(-34)$:

$f_1(-34) = 0.9*[169.65–1.3*5]+0.1*[\{-36-(-34+43.08-1.3*5)\}^2]^{½} = 147.47*$

$f_1(-34) = 0.9*[171.65–1.3*5]+0.1*[\{-36-(-34+45.08-1.3*5)\}^2]^{½} = 149.07$

$f_1(-34) = 0.9*[173.65–1.3*5]+0.1*[\{-36-(-34+47.08-1.3*5)\}^2]^{½} = 150.67$

$f_1(-34) = 0.9*[175.65–1.3*5]+0.1*[\{-36-(-34+49.08-1.3*5)\}^2]^{½} = 152.27$

$f_1(-34) = 0.9*[177.65–1.3*5]+0.1*[\{-36-(-34+51.08-1.3*5)\}^2]^{½} = 154.19$

Due to the realized deductions, the following state will be achieved after Stage 1. Hence, we now call these as Stage 2 values.

$f_1(-34)$ + FJ+ Realized Changes = -34+43.08-5*1.3 = 2.58 ~ 3 = $f_2$(New)

$f_1(-34)$ + FJ+ Realized Changes = -34+45.08-5*1.3 = 4.58 ~ 5 = $f_2$(New)

$f_1(-34)$ + FJ+ Realized Changes = -34+47.08-5*1.3 = 6.58 ~ 7 = $f_2$(New)

$f_1(-34)$ + FJ+ Realized Changes = -34+49.08-5*1.3 = 8.58 ~ 9 = $f_2$(New)

$f_1(-34)$ + FJ+ Realized Changes = -34+51.08-5*1.3 = 10.58 ~ 11 = $f_2$(New)

Hence, we look up for these states in the calculations for Stage 2. For Stage 2, we observe the following:

For $f_2$ (3) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 3 | 33.93 | Does Not Exist Since the State of 3 represents a condition that the private sector will quit | MAP = Nil<br>Objective Function = Nil |
| 3 | 34.33 | | |
| 3 | 34.73 | | |
| 3 | 35.13 | | |
| 3 | 35.53 | | |

For $f_2$ (5) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 5 | 33.93 | Does Not Exist Since the State of 5 represents a condition that the private sector will quit | MAP = Nil<br>Objective Function = Nil |
| 5 | 34.33 | | |
| 5 | 34.73 | | |
| 5 | 35.13 | | |
| 5 | 35.53 | | |

For $f_2$ (7) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 7 | 33.93 | Infeasible | MAP = 35.53 |
| 7 | 34.33 | Infeasible | |
| 7 | 34.73 | 1294.401382 | Objective Function = 1294.17 |
| 7 | 35.13 | 1294.201382 | |
| 7 | 35.53 | 1294.175101* | |

For $f_2$ (9) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 9 | 33.93 | Infeasible | MAP = 35.13 |
| 9 | 34.33 | 1292.601382 | |
| 9 | 34.73 | 1292.401382 | Objective Function = 1292.37 |
| 9 | 35.13 | 1292.375101* | |
| 9 | 35.53 | 1292.575101 | |

For $f_2$ (11) we observe that:

| State | MAP | Combined Objective Function | Optimal Decision |
|---|---|---|---|
| 11 | 33.93 | 1290.801382 | MAP = 34.73 |
| 11 | 34.33 | 1290.601382 | |
| 11 | 34.73 | 1290.575101* | Objective Function = 1290.57 |
| 11 | 35.13 | 1290.775101 | |

| | | | |
|---|---|---|---|
| 11 | 35.53 | 1290.975101 | |

We combine the optimal values of stage 1 with the optimal values for all the stages beyond stage 1 (in this case it is stage 2 to stage 6) we get the following:

$f_1(-34)$ = 147.47 + Infeasible = Infeasible ⟶ Relates to State of $f_2(3)$

$f_1(-34)$ = 149.07 + Infeasible = Infeasible ⟶ Relates to State of $f_2(5)$

$f_1(-34)$ = 150.67 + 1294.17 = 1444.85 ⟶ Relates to State of $f_2(7)$

$f_1(-34)$ = 152.27 + 1292.37 = 1444.65* ⟶ Relates to State of $f_2(9)$

$f_1(-34)$ = 154.19 + 1290.57 = 1444.76 ⟶ Relates to State of $f_2(11)$

As per the above calculation, we can conclude that as we start from Stage 1 with a state of -$34M, the private sector faced an annual deduction of $1.3M. Hence, after running the realization pass calculations between Stage 1 and Stage 2, we realize that before the start of Stage 2, adopting a MAP of 35.13 will be the best alternative since the objective function will take a value of $1444.65M and would be the minimum value when combined with $152.27M for stage 1.

Repeating the procedures to input simulated deduction in the model (as demonstrated in the section “During Stage 1”) and then calculating the new state as well as corresponding optimal values (as demonstrated in “After Stage 1, i.e., Stage2”), for all the remaining stages we get the optimal values for the randomly generated deductions.

## Appendix 12

## Determining Number of Iterations

Simulations must be repeated several times to build confidence in the answers. But, a question arises: How many times must the model be run to have a desirable confidence level in the answers?

Weiss (2004) shows that a sample size can be calculated using the following formula:

$$n = \left(\frac{0.5 \times Z_{\alpha/2}}{E}\right)^2$$

where,

n = Sample size

$Z_{\alpha/2}$ = Z score having an area of $\alpha/2$ to its right under the standard normal curve

E = Margin of error

In our case

$$\alpha/2 = \left(\frac{1-0.95}{2}\right) = 0.25$$

$Z_{\alpha/2} = 1.96$ (Obtained from standard normal tables)

E = 10%

Substituting these values in the equation for n, we get:

$$n = \left(\frac{0.5 \times 1.96}{0.1}\right)^2 = 96.04 \sim 97 \text{ samples}$$

Hence, if we run the model 97 times, the margin of error in our estimate of optimal MAP will be 0.1 or less; that is, at the most, plus or minus 10%. However the model was run for 1000 iterations for several sensitivity analyses since it was felt that running more iterations as necessary to have conclusive results.

Following table provides the number of samples that for various margins of errors.

**Table 20 Number of Samples Depending on Margin of Error (Significance of 5%)**

| Margin of Error | Number of Samples |
|---|---|
| 10% | 97 |
| 5% | 385 |
| 3.1% | 1,000 |
| 1% | 9,604 |
| 0.98% | 10,000 |

## Appendix 13

### Counting the Number of Calculations

Calculating number of calculations was important here since several scenarios calculations were done using simulations.

The base case model has $241M, $182M, $135M, $91M, $53M, $17M and $-34M as financial states on the upper bound. Similarly values of $189M, $139M, $100M, $64M, $35M, $7M and -36$M were observed on the lower bound. These bounds, thus gave rise to 52 (obtained by 241-189), 43, 35, 27, 18 and 10 states, respectively. Since from each state we have 5 MAPs we must perform 260 (obtained by 52*5), 215, 175,135 and 90 calculations, respectively. Adding all these calculations required us to perform 875 calculations to conduct one analysis. If we increase the accuracy up to $0.1M then we would be required to calculate 8750 calculations.

Thus for each simulation if we carry out just 100 iterations the calculations would increase by 100 times.

## References

AASHTO (2007) “Long-Term Financing Needs for Surface Transportation”. Report by Standing Committee on Finance and Administration.

Ashuri B., Kashani H., Molenaar K. R., and Lee S.(2010) “A Valuation Model for Choosing the Optimal Minimum Revenue Guarantee (MRG) in a Highway Project: A Real-Option Approach” ASCE Conf. Proc. 373, 125 (2010), DOI:10.1061/41109(373)125

Asmar M. E., Hanna A. S., Chang C. K., and Russell J. S. (2009) “Alliance Team Selection for Infrastructure Projects Using Monte Carlo Simulations” ASCE Conf. Proc. 339, 133 (2009), DOI:10.1061/41020(339)133

Allison. B. (2009) “Integrating Public and Private Tolling Operations” Presentation to the 22nd International Symposium on Freeway and Tollway Operations, Nossaman LLP.

AECOM (2007), “User Guidebook on Implementing Public-Private Partnerships for Transportation Infrastructure Projects in the United States,” Final Report Work Order 05-002, prepared for Office of Policy and Governmental Affairs, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

AECOM (2007). *Case Studies of Transportation Public-Private Partnerships in the United States*. Final Report Work Order 05-002. FHWA, U.S. Department of

Transportation. http://www.fhwa.dot.gov/ipd/pdfs/us_ppp_case_studies_final_report_7-7-07.pdf

AECOM (2007). *Case Studies of Transportation Public-Private Partnerships Around the World*. Final Report Work Order 05-002. FHWA, U.S. Department of Transportation. http://www.fhwa.dot.gov/ipd/pdfs/int_ppp_case_studies_final_report_7-7-07.pdf

Akintoye, A., Hardcastle, C., Beck, M., Chinyio, E. and Asenova, D. (2003). " Achieving Best Value In Private Finance Initiative Project Procurement". Journal of Construction Management and Economics. (July 2003) 21, 461-470

Akintoye A., Fitzgerald E., and Hardcastle C (1999). "Risk Management For Local Authorities' Private Finance Initiative Projects". Glasgow Caledonian University, RICS Research Foundation, COBRA, ISBN 0-85406-968-2.

Abdel, A. M. (2007). "Successful Delivery of Public-Private Partnerships for Infrastructure Development". Journal of Construction Engineering and Management. ASCE. 133(12), 918-931.

Abdel, A. M. (2007) "Successful Delivery of Public-Private Partnerships for Infrastructure Development". Journal of Construction Engineering and Management. ASCE. Vol 133, No.12, 2007, pp. 918-931.

Analysis in Comparing Public Private Partnerships to Traditional Procurements." Public Works Management and Policy, Vol. 13, No. 2, pp. 114–125.

Akintoye, A., Hardcastle, C., Beck, M., Chinyio, E. and Asenova, D. (2003). " Achieving Best Value In Private Finance Initiative Project Procurement". Journal of Construction Management and Economics. (July 2003) 21, 461-470

AECOM (2007), "User Guidebook on Implementing Public-Private Partnerships for Transportation Infrastructure Projects in the United States," Final Report Work Order 05-002, prepared for Office of Policy and Governmental Affairs, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

ACCA Members Survey (2002). "Do PFI Schemes Provide Value for Money?" The Association of Chartered Certified Accountants, UK.

ADBI (2008) "PPP Benefits" Presented at Seminar – "Private Sector Participation and Investment in Physical Infrastructure for CAREC" held in Tokyo.

Assessment of Projects for Procurement as Public Private Partnership (2006), Public Private Partnership, Ireland.

Bing L., Akintoye A., Edwards P. J. and Hardcastle C (2005) "The Allocation of Risk In PPP/PFI Construction Projects In The UK". International Journal of Project Management 23, 25-35.

Bel G. and Foote J. (2009) "Tolls, terms and public interest in road concessions privatization: a comparative analysis of recent transactions in the USA and France." Transport Reviews, Vol. 29, No. 3, 397–413.

Bain R. (2009) “Error and optimism Bias in toll Road Traffic forecasts” Journal of Transportation, 36:469-482, DOI 10.1007/s11116-009-9199-7. Springer Science + Business Media, LLC.

Buxbaum J. N. and Ortiz I (2009). “Public Sector Decision Making for Public Private Partnerships – A Synthesis of Highway Practice”. NCHRP Synthesis 391, Transportation Research Board.

Bing L., Akintoye A., Edwards P. J., and Hardcastle C. (2004) “The Allocation of Risk in PPP/PFI Construction Projects In The UK”. International Journal of Project Management 23 (2005) 25-35.

Brandao, L. E. T. and Saraiva, E. (2008). “The Option Value of Government Guarantees in Infrastructure Projects”. Journal of Construction Management and Economics. (November 2008), 26, 1171-1180.

British Columbia Partnerships (2003) “An Introduction to Public Private Partnerships”, British Columbia, Canada

Bertsimas D. and Thiele A. (2006) “A Robust Optimization Approach to Inventory Theory”. Operations Research, Vol. 54, No. 1, pp. 150-168, INFORMS.

Ben-Tal A, Bertsimas D. and Brown D. B. (2010) “A Soft Robust Model for Optimization Under Ambiguity”. Operations Research, Vol. 58, No 4., Part 2 of 2, pp. 1220-1234, INFORMS

Birge J. R. and Louveaux F. (1997). “Introduction to Stochastic Programming”. Second Edition. ISBN 978-0-387-98217-5. Springer-Verlag New York, Inc.

Brandao, L. E. T. and Saraiva, E. (2008). “The Option Value of Government Guarantees in Infrastructure Projects”. Journal of Construction Management and Economics. (November 2008), 26, 1171-1180.

Benli O. S. (1999) “Dynamic Programming,” Industrial Engineering Applications and Practice: Users Encyclopedia, Copyright 1999 International Journal of Industrial Engineering, retrieved from http://www.csulb.edu/~obenli/Research/IE-encyc/dynprog.html on 7th May, 2011.

Buxbaum J. N. and Ortiz I. N. (2007) “Protecting the Public Interest: The Role of Long-Term Concession Agreements for Providing Transportation Infrastructure”. Research Paper 07-02, The Keston Institute for Public Finance and Infrastructure Policy Research Paper Series Index.

CALTRANS (2007) “Life Cycle Cost Analysis Procedures Manual”. CALTRANS

Caltrans (2010) “Analysis of Delivery Options For the Presidio Parkway Project”. CTC Project Proposal Report Submission. Report Prepared by Arup/Parsons Brinkenhoff Joint Venture.

Cooper W. W., Seiford L. M. and Zhu J (2004) “Handbook on Data Envelopment Analysis”, Kluwer Academic Publishers, ISBN 1-4020-7797-1

Cook W. D. and Zhu. J. (2006) “Rank Order Data in DEA: A General Framework”, European Journal of Operational Research, 174, 1021-1038.

Cui. Q., and Lindly. J. (2010) “Evaluation of Public Private Partnership Proposals”, Report ALDOT 930-741, University Transportation Centre for Alabama (UTCA) and Alabama Department of Transportation (ALDOT)

Chiara, N. and Garvin, M. (2008). “Variance models for project financial risk analysis with applications to Greenfield BOT highway projects”. Journal of Construction Management and Economics. (September 2008) 26, 925-939

Cui Q., Sharma D. K., Farajian M., Perez M, and Lindly J (2010). “Feasibility Study Guideline for Public Private Partnership Projects”. Report No. 930-722R, ALDOT.

Cohon J.L. (1978) “Multiobjective Programming and Planning”. New York: Academic Press.

Chiara N., Garvin M. J. and Vecer J. (2007). "Valuing Simple Multiple-Exercise Real Options in Infrastructure Projects". Journal of Infrastructure Systems, Vol. 13, No. 2, pp. 97-104

Cui Q. and Lindly J (2010) "Evaluation of Public Private Partnership Proposals". Final Report, No 930-741, University Transportation Center for Alabama, ALDOT.

Cui Q. and Lindly J. (2010) "  Evaluation of Public Private Partnership Proposals" UTCA Report number 08402, ALDOT report 930-741, ALDOT

Cui Q., Sharma D. K., Farajian M., and Perez M. (2010) "Feasibility Study Guideline for Public Private Partnership Projects", UTCA, Report No. 930-722R, ALDOT.

CUPE (2009) "Evaluation of Public Private Partnerships – Costing and Evaluation Methodology." Prepared by Blair Mackay Mynett Inc., Canadian Union of Public Employees

CBO (2008) "Issues and Options in Infrastructure Investments - Appendix B" Congressional Budget Office. Document retrieved from http://www.cbo.gov/ftpdocs/91xx/doc9135/InfrastructureTOC.2.1.htm on November 1, 2010.

Davis R (2008) "Teaching Note – Teaching Project Simulation In Excel Using PERT-Beta Distribution," Vol 8. No. 3, pp. 139-148, issn1532-0545 08 0803 0139, INFORMS

Dochia S. and Parker M. (2009) "Introduction to Public-Private Partnerships With Availability Payment" Jeffrey A Parker & Associates, Inc.

Dick W. and Akintoye A (1996) "Private Finance Initiative Procurement Method" COBRA' 96, RICS Research, ISBN 0-85406-894-5.

Dochia S. and Parker M. (2009). "Introduction to Public Private Partnerships With Availability Payments". Jeffrey A Parker & Associates, Inc.

Davis R (2008). "Teaching Note- Teaching Project Simulation in Excel Using PERT-Beta Distributions" Vol. 8, No3, pp. 139-148, INFORMS.

Edkins A. J. and Smyth H. J. (2006) "Contractual Management in PPP Projects: Evaluation of Legal versus Relational Contracting for Service Delivery" Profl. Issues in Engrg. Educ. and Pract. 132, 82 (2006), DOI:10.1061/(ASCE)1052-3928(2006)132:1(82)

Edgeworth, F. Y. (1881) "Mathematical Physics", New York: Augustus M. Kelley.

Pareto, V. (1896). Cours D'Economie Politique, Vol. I and II (F. Rouge, Lausanne).

Evaluation of Public Private Partnerships – Costing and Evaluation Methodology (2009). Prepared by Blair Mackay Mynett Inc. Prepared for Canadian Union of Public Employees

Eschenbach E. A., Shoemaker C. A. and Caffey H. M (1995) "Parallel Algorithms for Stochastic Dynamic Programming with Continuous State and Control Variables" ORSA Journal On Computing, Vol. 7, No. 4, Fall 1995, pp. 386-401, DOI: 10.1287/ijoc.7.4.386

Engel E., Fischer R. and Galetovic A. (2011) "Public Private Partnership to Revamp U.S. Infrastructure". The Hamilton Project, Brookings

Eckhause J. M., Hugher D. R., and Gabriel S. A. (2009) "Evaluating Real Options for Mitigating Technical risk in Public Sector R&D Acquisitions". International Journal of Project Management 27 (2009) 365-377

FHWA (2007) "Case Studies of Public-Private Partnerships for Transportation Projects around the World" Task Order 05-002. Report prepared by AECOM Consult Team.

FHWA (2007b) "Case Studies of Public-Private Partnerships for Transportation Projects In The United States" Task Order 05-002. Report prepared by AECOM Consult Team.

FHWA (1998) "Life Cycle Cost Analysis in Pavement Design – In search of Better Investment Decisions." Pavement Division Interim Technical Bulletin.

Finnerty, J. D. (2007). "Project Financing". Second Edition. John Wiley & sons Inc.

FDOT (2007), "Request for Qualifications - Addendum # 2 With Rider", I-595 Corridor Roadway Improvements Project, Financial Management # 420809-3-52-01. Downloaded from FDOT website on October 10, 2010.Crooks E and Ramey K (2009) "Availability Payment Mechanisms For Transit Projects", KPMG LLP, US

FHWA (2009) “Public-Private Partnerships for Highway Infrastructure: Capitalizing on International Experience”. Report No. FHWA-PL-09-010.

FHWA (2007). “International PPP Case Studies Report” Prepared by AECOM TEAM, Task Order 05-002.

Garvin. M., Molenaar. K., Navarro. D., and Proctor G. (2011). “Key Performance Indicators in Public-Private Partnerships - A State-of-the-Practice Report” Report number FHWA-PL-10-029, FHWA.

FTA/NCPPP (1999) “PPPs and Use of Availability Payments”. Chicago, IL. PricewaterhouseCoopers LLP. Online Presentation retrieve on October 17, 2010 from http://www.ncppp.org/publications/TransitChicago_0905/Raymond%20Finance_Chi090519.pdf

FDOT (2009) “ I-595 Value for Money Analysis”, Prepared by Jeffery A Parker & Associates, Inc., Florida Department of Transportation.

FHWA (2009) “Special Experimental Projects No. 14 – Alternative Contracting”. Retrieved from http://www.fhwa.dot.gov/programadmin/contracts/sep_a.cfm on 10/18/2010.

FHWA (2009) “Public-Private Partnerships for Highway Infrastructure: Capitalizing on International Experience”. Report No. FHWA-PL-09-010.

FHWA (2004) “Report to Congress On Public Private Partnerships”. Retrieved from http://www.fhwa.dot.gov/reports/pppdec2004/#appg on 10/18/2010.

FHWA Website - “P3 Defined” Page retrieved from http://www.fhwa.dot.gov/ipd/p3/defined/index.htm on October 19, 2010.

FHWA Website – “Potential P3 Constraints” Page Retrieved from http://www.fhwa.dot.gov/ipd/how_business/fact_sheets/p3.htm on October 10, 2010.

FDOT (2009). “I-595 Corridor Roadway Improvements – Value for Money Analysis”

FHWA (2009) “Public-Private Partnerships for Highway Infrastructure: Capitalizing on International Experience”. Report No. FHWA-PL-09-010.

FHWA Fact-sheet (2010) “Public Private Partnerships” Page retrieved from http://www.fhwa.dot.gov/ipd/how_business/fact_sheets/p3.htm on October 10, 2010.

Fitch (2007). “Global Toll Rating Guidelines - Criteria Report.” Project Infrastructure and Project Finance. Fitch Ratings

FDOT (2006) “Port of Miami Tunnel and Access Improvement Project – Supplement to Project Information Memorandum”, Florida Department of Transportation.

Gabriel S. A., Sahakij P. and Balakrishnan S (2004) “Optimal Retailer Load Estimates Using Stochastic Dynamic Programming,” Vol. 130, No. 1 (1-17), Journal of Energy Engineering.

Gabriel. S. A., Sahakij. P. and Balakrishnan S (2004). “Optimal Retailer Load Estimates Using Stochastic Dynamic Programming”. Journal of Energy Engineering, Vol 130, No. 1, ASCE.

Gabriel S. A. (2009)- Lecture Presentations For ENCE603 At The University of Maryland.

Gabriel S. (2010). “Presentation for ENCE725 – Probabilistic Optimization”. University of Maryland

Gabriel S. A., Sahakij P, Ramirez M. and Peot C., (2007). "A Multiobjective Optimization Model for Processing and Distributing Biosolids to Reuse Fields," Journal of the Operational Research Society, 58, 850-864

Gabriel S. A., Kumar S., Ordonez J. and Nasserian A (2006a) “A Multiobjective Optimization Model For Project Selection With Probabilistic Considerations” Socio-Economic Planning Sciences, Elsevier, 40(4), 297-313.

Gabriel S. A., Ordonez J. F. and Faria J. A. (2006b)  “Contingency Planning in Project Selection Using Multiobjective Optimization and Chance Constraints” Journal of Infrastructure Systems, Vol. 12, No. 2, pp 112–120.

Garvin M. J. (2010) “Enabling Development of the Transportation Public-Private Partnership Market in the United States”, Journal of Construction Engineering and Management, Vol. 136, No. 4, ASCE.

GAO (1999) “Public-Private Partnerships – Terms Related to Building and Facility Partnerships”  United States Government Accountability Office, GAO/GGD-99-71.

GAO (1999). “Public Private Partnerships – Terms Related to Building and Facility Partnerships”. GAO/GGD-99-71.

GAO (2008) *“Highway Public-Private Partnerships: Securing Potential Benefits and Protecting the Public Interest Could Result from More Rigorous Up-Front Analysis”*. GAO-08-1052T, US Government Accountability Office.

GDOT (2010) “Georgia Department of Transportation – Public Private Partnerships” Page retrieved from http://www.dot.state.ga.us/informationcenter/p3/Documents/P3%20Guidelines-Appendices.pdf  on 20th October, 2010.

GAO (2008). “Securing Potential Benefits and Protecting the Public Interest Could Result from More Rigorous Up-Front Analysis”. United States Government Accountability Office. GAO-08-1052T

Galilea P and Medda F (2010), Does The Political And Economic Context Influence The Success Of A Transport Project? An Analysis Of Transport Public-Private Partnerships”, Research in Transportation Economics, Volume 30, Issue 1, ECONOMICS OF CONTRACTUAL RELATIONSHIPS IN THE PROVISION OF TRANSPORT INFRASTRUCTURE, 2010, Pages 102-109, ISSN 0739-8859

Garvin M (2010) "Enabling Development of the Transportation Public-Private Partnership Market in the United States". J. Constr. Engrg. and Mgmt. Volume 136, Issue 4, pp. 402-411.

Ghavamifar K. and Touran A. (2008) "Alternative Project Delivery Systems: Applications and Legal Limits in Transportation Projects" J. Profl. Issues in Engrg. Educ. and Pract. 134, 106 (2008), DOI:10.1061/(ASCE)1052-3928(2008)134:1(106)

Gross, M. E. and Garvin M. J. (2009). "Approaches For Structuring Concession Lengths and Toll Rates For Transportation Infrastructure PPPs". Construction Research Congress, ASCE, 191-200

"Government Response to Public Accounts and Estimates Committee Report on private investment in public infrastructure" (2006), Published by Government Printer of the State of Victoria, retrieved from internet on 08/10/09

Government of India (2010) "Developing Toolkits for Improving Public Private Partnership Decision Making Processes – User Guide," Prepared by World Bank, PPIAF, Australian Government and Government of India.

Gustavo Nombela, Gines de Rus, Flexible-term contracts for road franchising, Transportation Research Part A: Policy and Practice, Volume 38, Issue 3, March 2004, Pages 163-179, ISSN 0965-8564

Gunhan S. (2009) "The Last Decade Analysis and the Near Future Trends in International Construction" ASCE Conf. Proc. 339, 33 (2009), DOI:10.1061/41020(339)33

Ho S. P. (2006) "Model for Financial Renegotiation in Public-Private Partnership Projects and Its Policy Implications: Game Theoretic View" J. Constr. Engrg. and Mgmt. 132, 678 (2006), DOI:10.1061/(ASCE)0733-9364(2006)132:7(678)

HM Treasury (2000) "Public Private Partnerships: The Government's Approach", The Stationery Office, Crown Copyright 2000, London.

HM Treasury (2006) "Value for Money Assessment Guidance". London

Hall. D. (2009) "A Crisis For Public-Private Partnerships (PPPs)?", Public Services International Research Unit (PSIRU).

HM Treasury Website (http://www.hm-treasury.gov.uk/ppp_index.htm) webpage visited on 08/2/09.

HM Treasury (2000) "Public Private Partnerships: The Government's Approach", The Stationery Office, Crown Copyright 2000, London.

HM Treasury (2006) "Value for Money Assessment Guidance". London

Ireland Public Private Partnership website www.ppp.gov.ie

Infrastructure Australia (2008) “National Public Private Partnership Guidelines, Volume 1: Procurement Options Analysis”, Australian Government.

Iyer K. C. and Sagheer M (2010)”Hierarchical Structuring of PPP Risks Using Interpretative Structural Modeling” J. Constr. Engrg. and Mgmt. 136, 151 (2010), DOI:10.1061/(ASCE)CO.1943-7862.0000127

Jin X. H. and Zhang G (2010) “Modelling Optimal Risk Allocation In PPP Projects Using Artificial Neural Networks”, International Journal of Project Management, In Press, Corrected Proof, Available online 25 August 2010, ISSN 0263-7863

Jin X H (2010) “Determinants of Efficient Risk Allocation in Privately Financed Public Infrastructure Projects in Australia”. J. Constr. Engrg. and Mgmt. 136, 138 (2010), DOI:10.1061/(ASCE)CO.1943-7862.0000118

Jin X. H. (2010)“Neurofuzzy Decision Support System for Efficient Risk Allocation in Public-Private Partnership Infrastructure Projects” J. Comp. in Civ. Engrg. 24, 525 (2010), DOI:10.1061/(ASCE)CP.1943-5487.0000058

Jose Manuel Vassallo, The role of the discount rate in tendering highway concessions under the LPVR approach, Transportation Research Part A: Policy and Practice, Volume 44, Issue 10, December 2010, Pages 806-814, ISSN 0965-8564

Koppinen, T. and Lahdenpera, P. (2007). “Realized Economic Efficiency of Road Project Delivery Systems”. Journal of Infrastructure Systems. ASCE 13(4), 321-329.

Kriger D., Shiu S. and Naylor S. (2007) “Estimating Toll Road Demand And Revenue” NCHRP Synthesis 364, Transportation Research Board.

Ke Y., Wang S., and Chan A. P. C. (2010), “Risk Allocation in Public-Private Partnership Infrastructure Projects: Comparative Study” J. Infrastruct. Syst. 16, 343 (2010), DOI:10.1061/(ASCE)IS.1943-555X.0000030

Kessler F. W. (2011) “Public-Private Partnerships for California Transportation” Nossaman LLC, Presentation at NCPPP Conference: Implementing Partnerships in California, Sacramento 01/20/2011.

Kwak Y. Hoon, Chih Y. Y. and Ibbs C. W. (2009). “Towards a Comprehensive Understanding of Public Private Partnerships for Infrastructure Development” California Management Review, Vol 51, No. 2.

Lindly J. K. and Clark P. R. (2004). “Characterizing Work Zone Configurations and Effects”. University Transportation Centre for Alabama, ALDOT Research Project No. 930-603.

Lui, J. and Cheah, C. Y. J. (2009). “Real Option Application in PPP/PFI Project Negotiation”. Journal of Construction Management and Economics. (April 2009) 27, 331-342.

Li. M, Azarm S. and Boyars A (2006). “A new Deterministic Approach Using Sensitivity Region Measures for Multi-Objective Robust and Feasibility Robust Design Optimization” Vol. 28. pp 874 to 883, Journal of Mechanical Design, ASME.

Leighland and Shugart (2008) “Is The Public Sector Comparator Right For Developing Countries”. Gridlines Note No 4, PPIAF.

Mantel S. J., Jack R. Meredith J. R. Scott M. Shafer S. M. and Sutton M. M. (2007) “Project Management in Practice” 3rd Edition, Published by Wiley, ISBN 0470121645.

Mallett W. J. (2008) “Public-Private Partnerships in Highway and Transit Infrastructure Provision”, Congressional Research Service Report to Congress, Order Code RL34567, July 9, 2008, Washington D.C.

McCowan A. K. and Mohamed S.(2007)“Decision Support System to Evaluate and Compare Concession Options” J. Constr. Engrg. and Mgmt. 133, 114 (2007), DOI:10.1061/(ASCE)0733-9364(2007)133:2(114)

Mostafa. K., Farnad. N., and Majid A. (2010), "Using Fuzzy-Delphi technique to determine the concession period in BOT projects," Information and Financial Engineering (ICIFE), 2010 2nd IEEE International Conference on , vol., no., pp.442-446, 17-19 Sept. 2010

Murray. S. (2006). Value for Money? – Cautionary Lessons About P3s From British Columbia. Canadian Centre for Policy Alternatives – BC Office.

Murray. S. (2006). “Value for Money? – Cautionary Lessons About P3s From British Columbia.” Canadian Centre for Policy Alternatives – BC Office.

Czerwinski. D., & Geddes R. R. (2010). “Policy Issues in U.S. Transportation Public-Private Partnerships: Lessons from Australia”. Mineta Transportation Institute, Report Sponsored by U.S. Department of Transportation, University Transportation Centers Program and the California Department of Transportation. Report - CA-MTI-10-2807.

NCCP (2006) “Statement Submitted By National Council for Public Private Partnerships to the National Surface Transportation Policy and Revenue Study Commission”. Prepared by Norment R.

“Mythbusters – Facts And Fictions About Public Private Partnerships” (2007). Online resource on Partnerships Victoria website, State Government of Victoria, Australia.

NCPPP – “Types of Partnerships” Retrieved from http://www.ncppp.org/howpart/ppptypes.shtml on 1/24/2011.

NCPPP (2002) “For The Good Of The People: Using Public-Private Partnerships To Meet America’s Essential Needs”, National Council for Public-Private Partnerships, Washington, DC.

NCHRP Report 688 “Determining Highway Maintenance Costs”, Transportation Research Board of the National Academies.

Ng. A., and Loosemore M (2007). “Risk Allocation In The Private Provision of Public Infrastructure”  International Journal of Project Management 25 (2007) 66-76.

Ng S. T. , Xie. J, Cheung. Y. K. and Jefferies M (2007a)“A simulation model for optimizing the concession period of public–private partnerships schemes”, International Journal of Project Management, Vol 25(8), 791-798.

Ng S. T., Xie J., Skitmore M., and Cheung Y. K. (2007b) “A fuzzy simulation model for evaluating the concession items of public–private partnership schemes” Automation in Construction 17 (2007) 22–29

Nair R. and Miller-Hooks E. (2009) “Evaluation of Relocation Strategies for Emergency Medical Service Vehicle” Transportation Research Record: Journal of the Transportation Research Board No. 2137, pp. 63–73.

Shin S. M., Franzese O., Greene D. L., Hwang H. L. and Gibson R. C. (2002) “Temporary Losses of Highway Capacity and Impacts on Performance,” Oak Ridge National Laboratory and University of Tennessee, ORNL/TM-2002/3.

Pakkala P. (2002). “Innovative Project Delivery Methods for Infrastructure – An International Perspective”. Finnish Road Enterprise, Headquarters, Helsinki, ISBN 952-5408-05-1.

PricewaterhouseCooper (2009) “PPPs and Use of Availability Payments” FTA/NCPPP, Chicago, IL.

Presidio Parkway Project (2010 a) "Analysis of Delivery Options for the Presidio Parkway Project," CTC Project Proposal Report, Arup PB Joint Venture, CALTRANS

Presidio Parkway Project (2010 b) Public Private Agreement, Volume II, Division I.

Presidio Parkway Financial Proposal (2010). Retrieved from http://www.dot.ca.gov/hq/esc/oe/project_ads_addenda/04/04-1637U4/P3Agt_Executed/ on 11/15/2011

Pakkala P (2002). "Innovative Project Delivery Methods for Infrastructure – An International Perspective". Finnish Road Enterprise, Helsinki.

Parker Michael (2010). "Emerging Trends for Raising Capital Workshop DBOM/Availability Payments" Jeffrey A Parker & Associates, Transportation Research Board.

Parker M (2011) "Availability Payments and Other Forms of P3s For Surface Transportation". The Forum on Funding and Financing Solutions for Surface Transportation in the Coming Decade – Conference Report, AASHTO Centre for Excellence in Project Finance.

"Public Accounts and Estimates Committee – Report on private investment in Public Infrastructure", retrieved from Partnerships Victoria website on 08/10/09

Pakkala P. (2002) "Innovative Project Delivery Methods For Infrastructure – An International Perspective" Helsinki 2002, Finnish Road Enterprise, ISBN 952-5408-05-1

Partnerships Victoria (2001) “Public Sector Comparator – Technical Note”, Published by Partnerships Victoria

PEW (2009) “Driven By Dollars: What States Should Know When Considering Public-Private Partnerships to Fund Transportation” Report by The Pew Charitable Trusts.

Power G., Burris M, Vadali S. and Vedenov D. (2009) “Valuation of Buyout Options in Comprehensive Development Agreements”. Texas Transportation Institute, Department of Transportation Research and Innovative Technology Administration, UTCM Project #08-04-12

“Public Accounts and Estimates Committee – Report on private investment in Public Infrastructure”, retrieved from Partnerships Victoria website on 08/10/09

Public Sector Comparator – Technical Note (June 2001), Published by Partnerships Victoria, Retrieved from internet on 08/01/09

Partnerships Victoria (2001) “Public Sector Comparator – Technical Note”. State of Victoria. ISBN 0 7311 1433 7.

Partnerships Victoria (2003) “Public Sector Comparator – Supplementary Technical Note”.

PPIAF (2009) “Toolkit for Public Private Partnerships in Roads and Highways,” Public Private Infrastructure Advisory Facility, World Bank.

Qian Q. and Kong R. T. L. (2009) “Catastrophe Risk Management for Private-Public Partnership (PPP) Infrastructure Projects”. ASCE Conf. Proc. 339, 73 (2009), DOI:10.1061/41020(339)73

Saage L. and Ajise K. (2010) “Presidio Parkway Project - Public Private Partnership” Presented at the NCPPP Workshop at Sacramento, CA January 20, 2011.

Saage L. and Ajise K. (2011) “Presidio Parkway Project  Public Private Partnership”. Presented at the NCPPP Workshop, Sacramento, California.

Sahakij P. (2008) “Multiobjective Optimization Models For Distributing Biosolids To Reuse Fields”. PhD Dissertation, University of Maryland.

Scott S., Molenaar K. R., Gransberg D. D., and Smith N. C. (2006) “Best-Value Procurement Methods for Highway Construction Projects”, NCHRP Report 561, Transportation Research Board of the National Academies.

Shah S. N. and Coleman L. (2009) ”Project Funding Opportunities” ASCE Conf. Proc. 343, 19 (2009), DOI:10.1061/41038(343)19

Skaf. J. and Boyd S. (Undated). “Design of Affine Controllers Via Convex Optimization”. Information Systems Lab, Electrical Engineering Department, Stanford University.

Sanghi, A., Sundakov, A., and Hankinson, D. (2007). "Designing and Using Public-Private Partnership Units in Infrastructure – Lessons From Case Studies Around The World". Article in Gridlines, PPIAF. Note No. 27

Sharma D. K. and Cui Q. (2009a). "Equity Allocation In PPP Projects Under Uncertainty" – Presentation at 3rd Annual Trans-Atlantic INFRADAY Conference, Washington DC.

Sharma D. K. and Cui. Q. (2009b). "Structuring Equity Investment in PPP Projects". Proceedings – LEAD 2009 Conference, South Lake Tahoe, California

Sharma D. K., Cui Q., Chen L and Lindly J. K. (2010). *"Balancing Private And Public Interests In PPP Contracts Through Equity Capital Structure Optimization."* Vol 2151/2010, Pages 60-66, DOI 10.3141/2151-08, Transportation Research Record (TRR), Journal of the Transportation Research Board.

Srinivasan G (2009) "Lecture Series on Fundamentals of Operations Research," Department of Management Studies, IIT Madras, Video Downloaded from http://www.youtube.com/watch?v=8F8ypYM-NlQ on 7th May, 2011.

Shen J and Wang S (2010) , "The Decision-Making Model of TOT Concession Period Based on Fuzzy Stochastic Petri Net," Management and Service Science (MASS), 2010 International Conference on , vol., no., pp.1-4, 24-26 Aug. 2010.

Shen L. Y., Bao H. J., Wu Y. Z., and Lu W. S. (2007) ”Using Bargaining-Game Theory for Negotiating Concession Period for BOT-Type Contract” J. Constr. Engrg. and Mgmt. 133, 385 (2007), DOI:10.1061/(ASCE)0733-9364(2007)133:5(385)

Silva C. and Lowy J. (2011). “States Struggle for Financing To Meet Road Needs”. Associated Press, Article Published in ENR, 9/17/ 2011.

Shen L. Y. and Wu Y. Z. (2005) “Risk Concession Model for Build/Operate/Transfer Contract Projects” J. Constr. Engrg. and Mgmt. 131, 211 (2005), DOI:10.1061/(ASCE)0733-9364(2005)131:2(211)

Tawiah P. A. and Russell A. D. (2008) “Assessing Infrastructure Project Innovation Potential as a Function of Procurement Mode” J. Mgmt. in Engrg. 24, 173 (2008), DOI:10.1061/(ASCE)0742-597X(2008)24:3(173)

Tereso A. P., Araújo M. M. T and Elmaghraby S. E. (2003). “Adaptive resource allocation in multimodal activity networks.” International Journal of Production Economics, Vol. 92 Issue 1, pp. 1-10.

TxDOT (2008). “TxDOT Public Private Feasibility Analysis Model – User Manual”

Schrank D., Lomax T., and Turner S. (2010) “TTI’s 2010 Urban Mobility Report”, Texas Transportation Institute.

TTI (2004) “Estimating Revenues Using A Toll Viability Screening Tool,” Report 0-4726-1, Project 0-4726, Texas Department of Transportation, Federal Highway Administration and Texas Transportation Institute.

Tillman R. (1997) “Shadow Tolls and Public-Private Partnerships For Transportation Projects”. The journal of Structured Finance, Vol 3, No 2: pp. 30-37

USDOT (2004) “Report To Congress On Public Private Partnerships”

USDOT (2007) “Report to Congress on the Costs, Benefits, and Efficiencies of Public Private Partnerships for Fixed Guideway Capital Projects” Report to the Secretary of Transportation to the United States Congress Pursuant to 49 U.S.C. 5309(c)(6), USDOT.

U.S. DOT (2004) Report to Congress on Public-Private Partnerships. Cited in User Guidebook For Implementing Public-Private Partnerships For Transportation Infrastructure Projects In The United States. Final Report

Value for Money Report - For the Design, Construction, Financing, Operation and Maintenance of the Completion of Autoroute 25 In the Metropolitan Montreal Area (2007). Public Private Partnerships, Quebec.

VDOT (2005). “The Commonwealth of Virginia – Public Private Transportation Act of 1995 – Implementation Guidelines”

Vajda S. (1972). “Probabilistic Programming”. Academic Press, New York and London.

Value for Money Assessment Guidance (2006), published by HM Treasury, UK

Value for Money Quantitative Assessment Guide, published by HM Treasury, UK

Value For Money Quantitative Evaluation Spreadsheet, published by HM Treasury, UK

World Bank Toolkit – "Expected Benefits of PPPs" Page retrieved from http://rru.worldbank.org/Documents/Toolkits/Highways/1_overdiag/11/112.htm on October 31, 2010.

Winston W. L. (2004) "Operations Research: Applications and Algorithms" Fourth Edition, Brooks/Cole Thomson Learning, CA, USA. ISBN 0-534-38058-1.

Xu Y., Yeung J. F. Y., Chan A. P. C., Daniel W.M. Chan D. W. M., Wang S. Q. and Ke Y (2010a), Developing A Risk Assessment Model For PPP Projects In China - A Fuzzy Synthetic Evaluation Approach", Automation in Construction, Volume 19, Issue 7, November 2010, Pages 929-943, ISSN 0926-5805

Xu Y., Albert P. C. Chan A. P. C., and Yeung J. F. Y (2010b) "Developing a Fuzzy Risk Allocation Model for PPP Projects in China". J. Constr. Engrg. and Mgmt. 136, 894 (2010), DOI:10.1061/(ASCE)CO.1943-7862.0000189

Yescombe, E. R. (2007). "Public Private Partnerships Principles of Policy and Finance". Edition 1, Yescombe Consulting Ltd., Published by Elsevier Ltd., Great Britain.

Yuan J, Skibniewski M. J., Li Q, and Zheng L, J. (2010) " Performance Objectives Selection Model in Public-Private Partnership Projects Based on the Perspective of Stakeholders" Mgmt. in Engrg. 26, 89 (2010), DOI:10.1061/(ASCE)ME.1943-5479.0000011

Zhang, X. (2005a). "Paving the Way for Public-Private Partnerships in Infrastructure Development". Journal of Construction Engineering and Management. ASCE, 131(6), 631-644.

Zhang, X. (2005b). "Criteria for Selecting the Private-Sector Partner in Public-Private Partnerships". Journal of Construction Engineering and Management. ASCE, 131(1), 71-80.

Zhang, X. (2005c). "Financial Viability Analysis and Capital Structure Optimization in Privatized Public Infrastructure Projects". Journal of Construction Engineering and Management. ASCE, 131(6), 656-668.

Zhang, X. Q., and Kumaraswamy, M. M. (2001). "Procurement Protocols for Public-Private Partnered Projects". Journal of Construction Engineering and Management. ASCE 127(5), 351-358.

Zhang, X. (2006). "Public Clients' Best Value Perspective of Public Private Partnerships in Infrastructure Development". Journal of Construction Engineering and Management. ASCE, 132(2), 107-114.

Zhang X (2009), “Best Value Concessionaire Selection Through A Fuzzy Logic System”, Expert Systems with Applications, Volume 36, Issue 4, May 2009, Pages 7519-7527, ISSN 0957-4174, DOI: 10.1016/j.eswa.2008.09.039.

Zhang X. Q., Kumaraswamy M. M., Zheng W., and Palaneeswaran E.(2002) “Concessionaire Selection for Build-Operate-Transfer Tunnel Projects in Hong Kong” J. Constr. Engrg. and Mgmt. 128, 155 (2002), DOI:10.1061/(ASCE)0733-9364(2002)128:2(155)

Zhang X. Q. and Kumaraswamy M. M. (2001), “Procurement Protocols for Public-Private Partnered Projects” J. Constr. Engrg. and Mgmt. 127, 351 (2001), DOI:10.1061/(ASCE)0733-9364(2001)127:5(351)

**Abbreviations**

FHWA – Federal Highway Administration

SEP-14 – Special Experimental Project 14

ISTEA – Intermodal  Surface Transportation Efficiency Act

USDOT – United States Department of Transportation

CBO – Congressional Budget Office

GAO - Government Accountability Office

NCHRP – National Cooperative Highway Research Program

WACC – Weighted Average Cost of Capital

BVSS – Best Value Source Selection

BVCS – Best Value Contributing Factors

MTG – Minimum Traffic Guarantee

MAP – Maximum Availability Payment

ORNL – Oak Ridge National Laboratory

IRR – Internal Rate of Return

MARR – Minimum Acceptable Rate of Return

DB – Design Build

DBFOM – Design Build Finance Operate and Maintain

DBOM – Design Build Operate and Maintain

BOT – Build Operate and Transfer

PPIAF – Public-Private Infrastructure Advisory Facility

TxDOT – Texas Department of Transportation

TTI – Texas Transportation Institute

NCPPP – National Council for Public Private Partnerships

P3FAST – P3 Feasibility Analysis Toolkit

DSS – Decision Support System

SDP – Stochastic Dynamic Programming

MOLP – Multi-objective Linear Programming

MODDP – Multi-objective Deterministic Dynamic Programming

MOSDP – Multi-objective Stochastic Dynamic Programming

MO$\tilde{S}$DP – Multi-objective Simulated Dynamic Programming

BVO – Best Value Objectives

GLP – Golden Link Partners

VfM – Value for Money

IRR – Internal Rate of Return

MARR – Minimum Acceptable Rate of Return

PCM – Post Concession Maintenance

LCC – Life Cycle Costs

$CFS_t$ = Control Financial State at time t

$FSA_t$= Financial State Achieved at time t

O&M – Operations and Maintenance

MARR – Minimum Acceptable Rate or Return

TIFIA - The Transportation Infrastructure Finance and Innovation Act

**Glossary**

Sources

1. Project Finance Portal (http://www.people.hbs.edu/besty/projfinportal/glossary.htm)
2. Cui et al (2010)
3. Yescombe, E. R. (2007)
4. TheFreeDictionary.com
5. NCHRP Synthesis 364
6. NCHRP Report 561
7. The National Council for Public Private Partnership (NCPPP)

**Concession**: A grant of a tract of land made by a government or other controlling authority in return for stipulated services or a promise that the land will be used for a specific purpose**. OR** *"This type of PPP is known as a Concession: that is, a 'user pays' model in which a private-sector party (the Concessionaire) is allowed to charge the general public Service Fees for using the Facility—for example the payment of a toll for using a bridge, tunnel or road. The toll reimburses the Concessionaire for the cost of building and operating the Facility, which usually reverts to public-sector control at the end of the Concession period."* (Yescombe, 2007)

**Shadow Tolling**: Shadow tolls are per vehicle amounts paid to a facility operator by a third party such as a sponsoring governmental entity. Shadow tolls are not paid by facility users. Shadow toll amounts paid to a facility operator vary by contract and are typically based upon the type of vehicle and distance traveled.

**Equity Cash Flow**: Cash flow available to equity holders. It is equal to net income plus depreciation less capital expenditures less increases in net working capital (NWC) less principal repayment plus new debt proceeds.

**Availability Payment Mechanism**: For the purpose of this research an Availability Payments Mechanism is defined as – the mechanism by which the private sector is reimbursed by the public sector. It consists of payments (in $M) and duration (in years).

**Ramp Up Period:** Time for traffic volumes to reach their full potential, without considering growth, after the opening of a new toll facility. The ramp-up period, which can last for several years, is the time it takes for users to become aware of the new toll road, change their travel patterns accordingly, and recognize the potential time-savings of using the new toll road

**Cash Flow:** Cash flow is cash receipts minus cash disbursements from a given operation or asset for a given period. A cash flow statement shows all sources and uses of cash reflected in the balance sheet cash account from one period to the next. (OR) It's the cash generated by a project.

**Equity**: The portion of the project's capex contributed by the investors to the Project Company, either as share capital or subordinated debt.

**DSR or DSRA**: Debt Service Reserve Account, a Reserve Account with a cash balance sufficient to cover the next scheduled debt service payment.

**Debt**: The obligation to repay an agreed amount of money.

**Debt Capacity:** The total amount of debt a company can prudently support given its earnings expectations, equity base, and asset liquidation value.

**Debt Service:** Principal repayments plus interest payable; usually expressed as the annual amount due per calendar or financial year.

**Discount Rate:** The annual percentage rate used to determine the present value of future cash flows.

**Financial Close:** The date on which all project contracts and financing documentation are signed and conditions precedent to initial drawing of the debt have been satisfied or waived.

**Internal Rate of Return (IRR):** The discount rate that makes the net present value equal to zero. Multiple IRRs occur mathematically if the periodic cash flows change signs more than once.

**Minimum Acceptable Rate of Return (MARR)** : It is the is the minimum rate of return on a project a manager or company is willing to accept before starting a project, given its risk and the opportunity cost of forgoing other projects.

**Best Value**: A procurement process where price and other key factors are considered in the evaluation and selection process to minimize impacts and enhance the long-term performance and value of construction.

**Design-Build (DB):** A DB is when the private partner provides both design and construction of a project to the public agency. This type of partnership can reduce time, save money, provide stronger guarantees and allocate additional project risk to the private sector. It also reduces conflict by having a single entity responsible to the public owner for the design and construction. The public sector partner owns the assets and has the responsibility for the operation and maintenance.

**Design-Build-Operate (DBO)**: A single contract is awarded for the design, construction, and operation of a capital improvement. Title to the facility remains with the public sector unless the project is a design/build/operate/ transfer or design/build/own/operate project.

**Design-Build-Operate-Maintain (DBOM):** The design-build-operate-maintain (DBOM) model is an integrated partnership that combines the design and construction responsibilities of design-build procurements with operations and maintenance. These project components are procured from the private section in a single contract with financing secured by the public sector. The public agency maintains ownership and retains a significant level of oversight of the operations through terms defined in the contract.

**Design Build Finance Operate and Maintain (DBFOM)**: With the Design-Build-Finance-Operate-Maintain (DBFOM) approach, the responsibilities for designing, building, financing, operating and maintaining are bundled together and transferred to private sector partners.

**TIFIA Program:** The Transportation Infrastructure Finance and Innovation Act (TIFIA) program provides Federal credit assistance in the form of direct loans, loan guarantees, and standby lines of credit to finance surface transportation projects of national and regional significance.

**Value for Money (VFM):** VfM takes the public cost comparator beyond just producing a market value for the project, but instead computes if there will be a return on investment, or value for money, to the end-users it does this by comparing the results with competitive bids from private firms.